LNA Design Training

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Agenda

- LNA Design Theory
- LNA Design Flow & Methodology
- Key Performance Parameters and Specification
- How to Design the LNA
- Using MWO for LNA – Import Device S-Parameters
- Characterize & add graphs / measurements to look at:
  - Gain – Gmax, MSG, G_A, G_T,
  - Noise Figures - NF and NFmin
  - Stability figures: K, B1
- Smith Chart Graphs and Circle Measurements
  - Stability Circles, Gain Circles, NF Circles
- Layout Design
- Tuning / Optimization
- Circuit - EM Simulation?

Linear Simulation

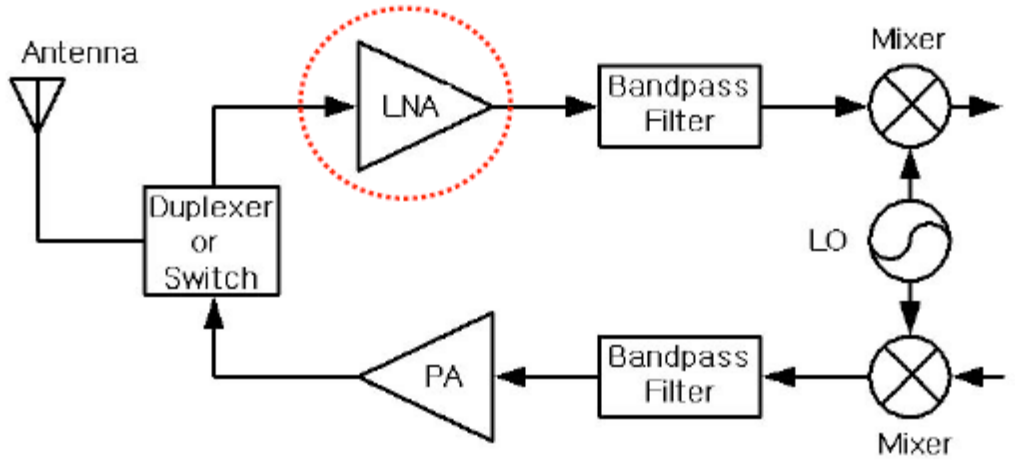
- Linear Simulation solves for S-parameters in the frequency domain at ports.
  - Internally, it solves the Y matrix.

- It is an ideal choice for anything based on S-parameters:
  - Linear Amplifier Analysis
  - Filter Analysis
  - Passive Component Analysis
  - Linear Noise Analysis
  - 2 Port Stability Analysis
  - Circle Measurements – Gain, Stability, Noise Figure Circles

Low Noise Amplifier

What is Low Noise Amplifier (LNA) ?

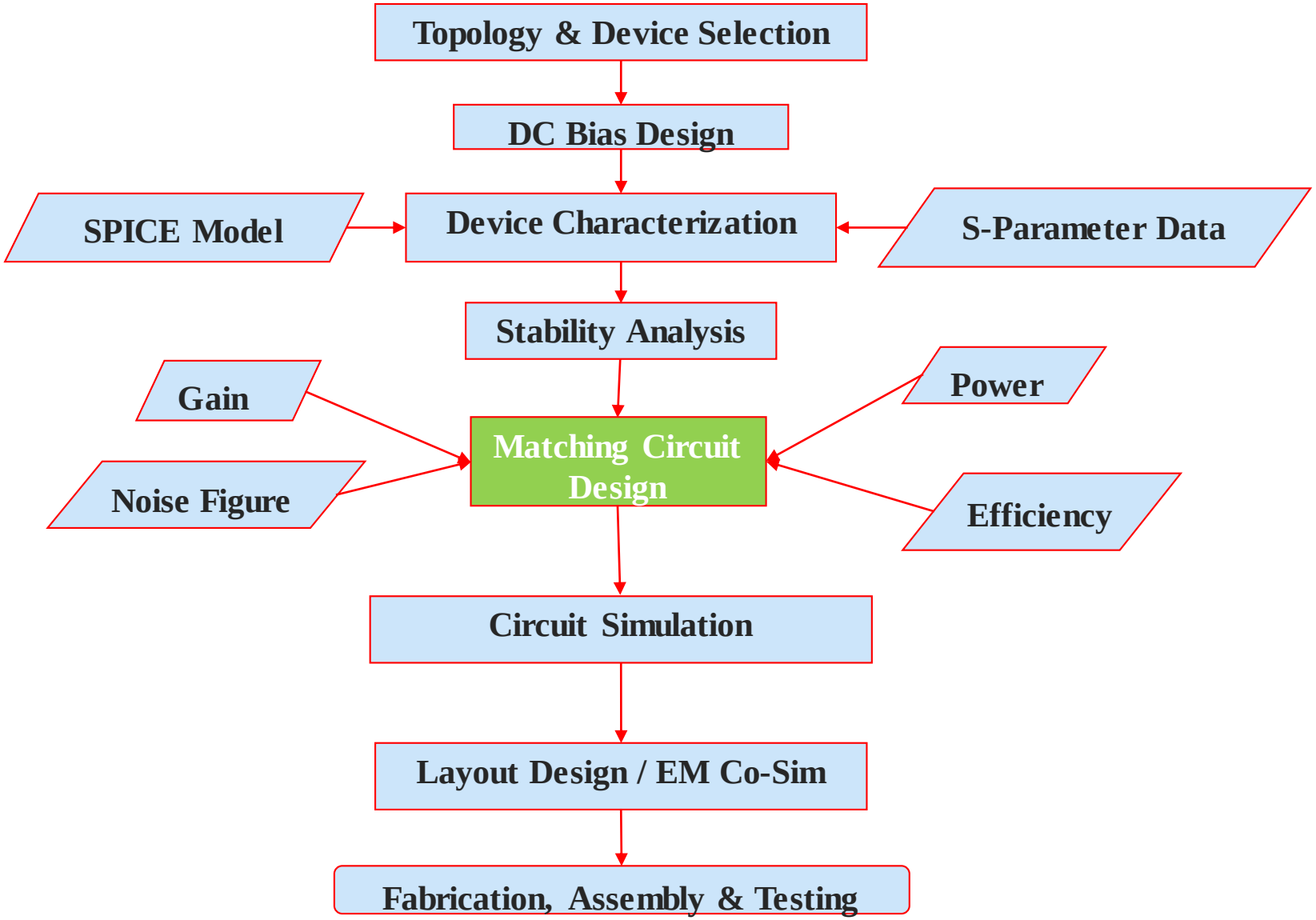
- Amplifier which increases the desired signal amplitude without adding distortion or noise.
- A preamplifier with a low noise figure in the receiver
- LNA determines noise figure, input return loss, and linearity of the overall Receiver



Small Signal Amplifier Design (LNA)

- *Small signal design usually based on transistor s-parameters*
- *S-parameters are dependent upon frequency and bias conditions*
- *Transistor selection for required NF, Gain, output power, frequency range, etc…*
- *Stability Considerations*
- Matching network Design for Gain & NF
- Layout
- EM-Circuit Co-Simulation

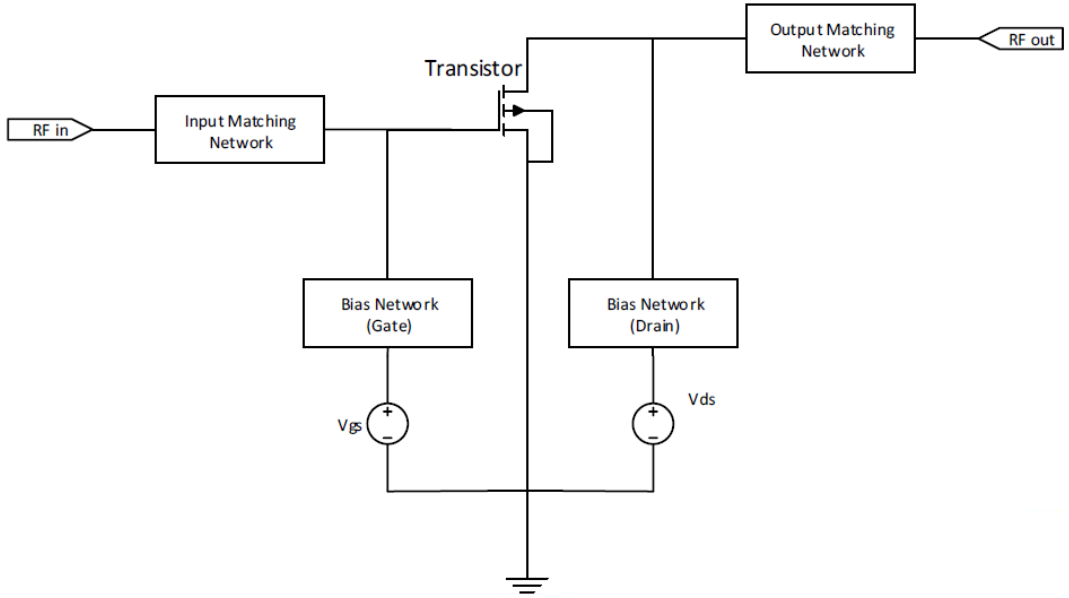
RF Amplifier Design Flow

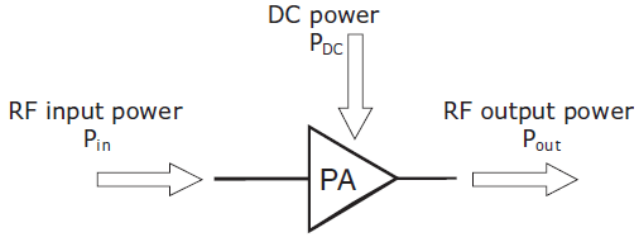


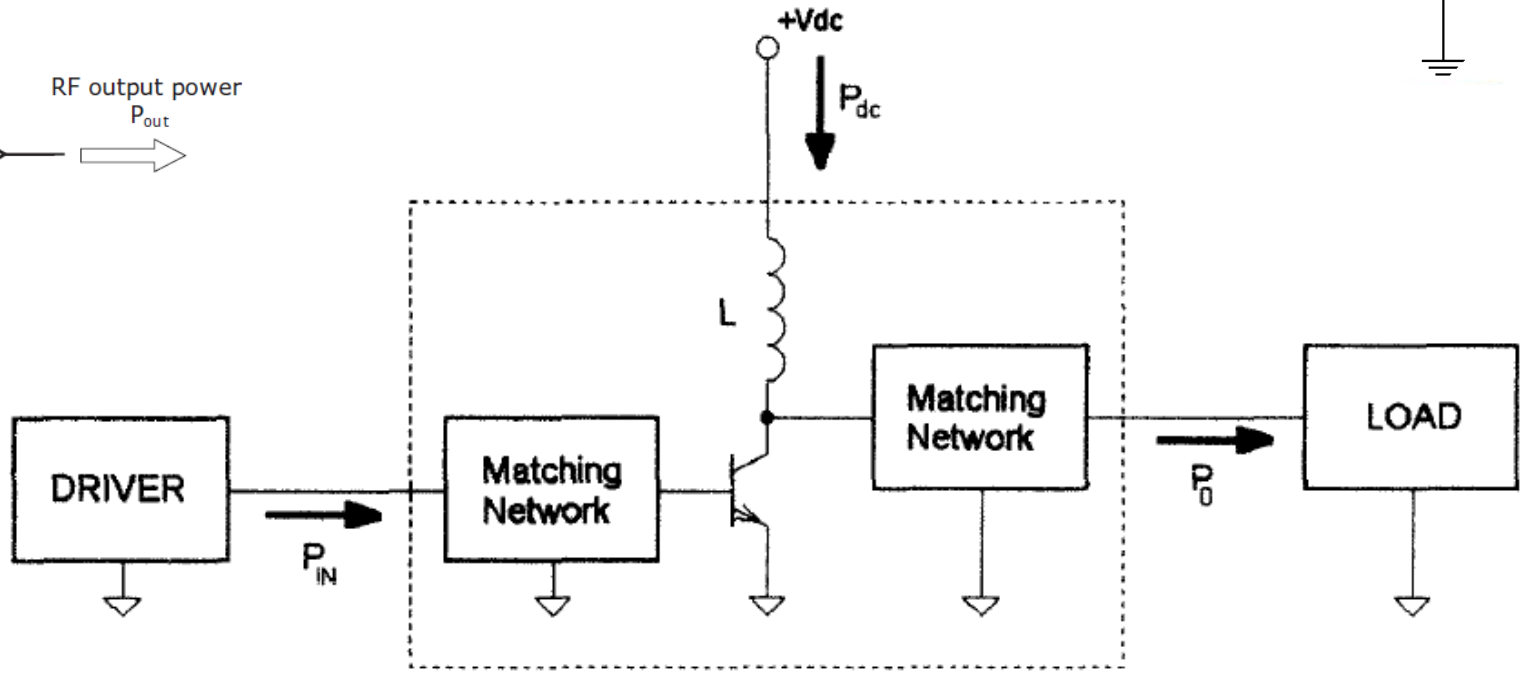
RF Amplifier Design Flow

Amplifier design - three-step process:

1. DC design
2. RF design
3. Total schematic layout







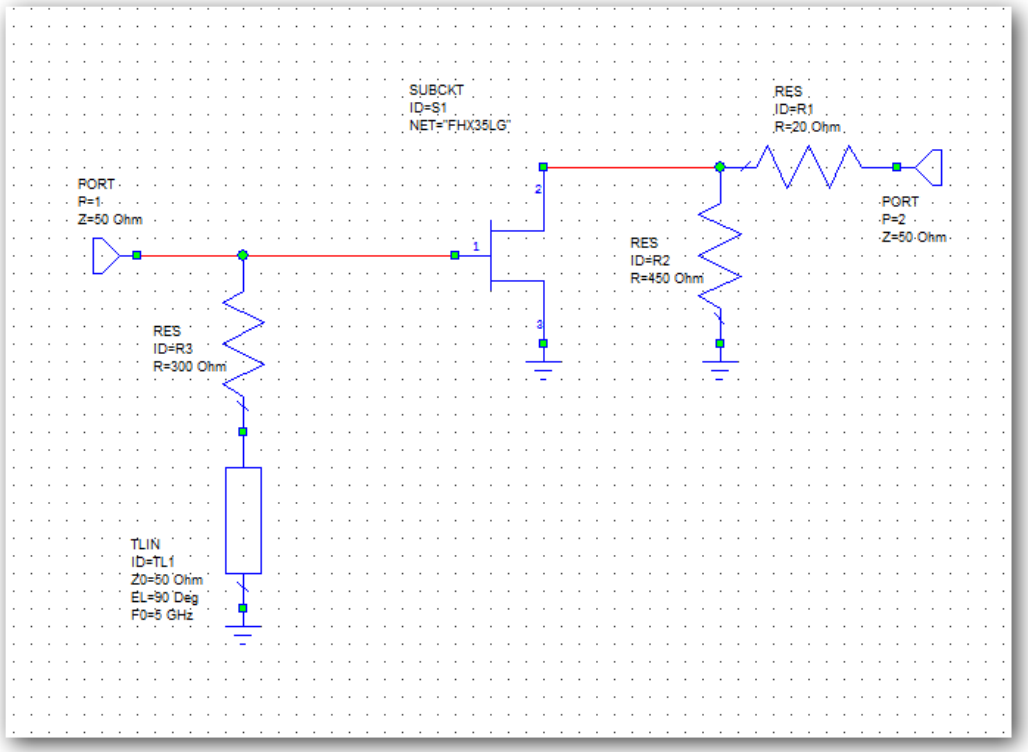
LNA Performance & Specifications

- Design Goals of a 5 GHz Narrow Band LNA
  - Noise Figure < 1.15 (1.2 in dB)
  - Gain > 10 dB
  - Input / Output RL
  - P1dB
  - IP3
  - Size ?

A Note on the Design

We are not including a biasing network – as we are using S-parameters for the FET model.

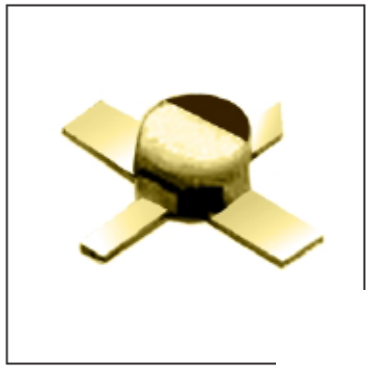
We also are making a unilateral matching network.



Transistor Device

FHX35LG

Super Low Noise HEMT



FEATURES

- Low Noise Figure: 1.2B (Typ.)@f=12GHz
- High Associated Gain: 10.0dB (Typ.)@f=12GHz
- Lg ≤ 0.25μm, Wg = 280μm
- Gold Gate Metallization for High Reliability
- Cost Effective Ceramic Microstrip (SMT) Package
- Tape and Reel Packaging Available

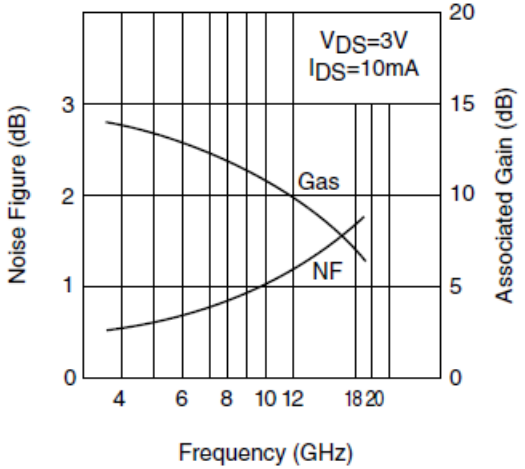
DESCRIPTION

The FHX35LG is a High Electron Mobility Transistor(HEMT) intended for general purpose, low noise and high gain amplifiers in the 2-18GHz frequency range. This device is packaged in cost effective, low parasitic, hermetically sealed(LG) or epoxy-sealed(LP) metal-ceramic packages for high volume telecommunication, DBS, TVRO, VSAT or other low noise applications.

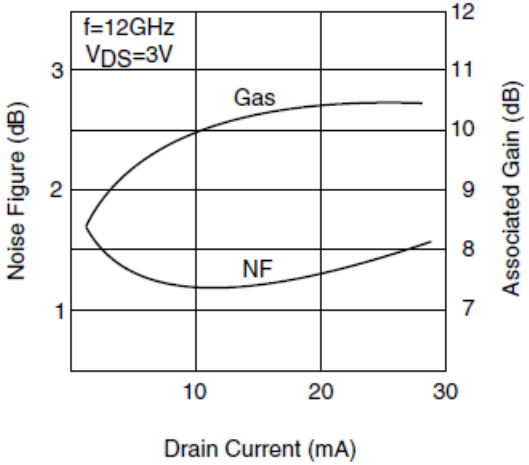
ELECTRICAL CHARACTERISTICS (Ambient Temperature Ta=25°C)

Item	Symbol	Test Conditions	Limit			Unit
			Min.	Typ.	Max.	
Saturated Drain Current	I_{DSS}	V_{DS} = 2V, V_{GS} = 0V	15	40	85	mA
Transconductance	gm	V_{DS} = 2V, I_{DS} = 10mA	40	60	-	mS
Pinch-off Voltage	V_p	V_{DS} = 2V, I_{DS} = 1mA	-0.2	-1.0	-2.0	V
Gate Source Breakdown Voltage	V_{GSO}	I_{GS} = -10μA	-3.0	-	-	V
Noise Figure	NF	V_{DS} = 3V, I_{DS} = 10mA f = 12GHz	-	1.2	1.6	dB
Associated Gain	G_{as}		8.5	10.0	-	dB
Thermal Resistance	R_{th}	Channel to Case	-	220	300	°C/W

NF & Gas vs. FREQUENCY



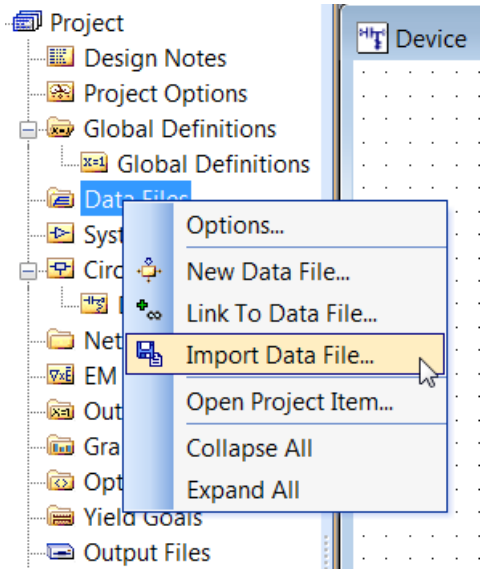
NF & Gas vs. I_{DS}

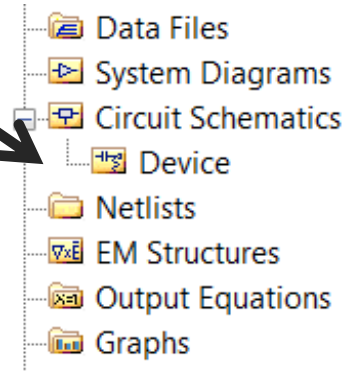


Create the Schematic

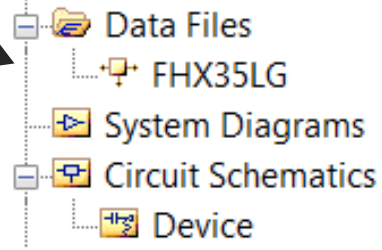
Step 1: Create a Schematic " Device" in a new project

Step 2: Import the S parameter data set for the HEMT transistor – "FHX35LG.s2p"





Right Click on Data Files to Bring it in.



Tip: Make sure you're looking for Touchstone files - or you might not see the file in the directory.

A Note on Data Files

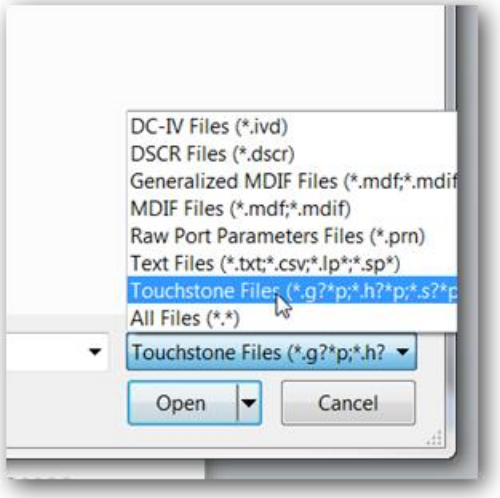
Microwave Office allows you to import different data types.

You select them – by picking the type when you bring in the data file.

The easiest choice is Touchstone 50 Ohms.

For example – if brining in data from 3D EM simulators – renormalize to 50 Ohms, before bringing in the data.

Then, there will be no confusion.



The S Parameters

Step 3: Look at the S parameters for the device.

Double click on the data file - to see the S parameters and the Noise data.

The S parameters are from 100 MHz to 20 GHz

The noise data are from 2 to 18 GHz.

Tip; The file can be edited. Be careful!

Sometimes this is useful if you want to add a DC point.

FHX35LG (Touchstone)

```
! fhx35lg.s2p  4/90
! FHX35LG
! @3V-10mA
! .1GHZ 20GHZ 22
# GHZ S MA R 50
! S-parameter data
    .100    .996    -3.5   4.576   177.2    .002    81.2    .516    -2.5
    .500    .994   -12.1   4.548   169.0    .012    79.3    .517   -10.2
   1.000    .982   -23.5   4.471   158.5    .023    73.1    .513   -19.9
   2.000    .950   -44.7   4.304   139.3    .043    57.9    .498   -38.0
   3.000    .912   -64.6   4.026   121.0    .059    44.6    .483   -54.9
   4.000    .867   -84.0   3.742   103.1    .071    31.8    .462   -71.9
   5.000    .821  -101.6   3.436    86.6    .079    20.0    .446   -87.6
   6.000    .783  -117.5   3.132    71.6    .085     9.8    .439  -102.2
   7.000    .757  -130.9   2.881    57.9    .087     0.9    .441  -115.3
   8.000    .738  -142.8   2.659    45.0    .088    -7.1    .452  -126.7
   9.000    .726  -153.8   2.497    32.4    .090   -15.3    .468  -136.9
  10.000    .707  -164.5   2.347    20.2    .092   -21.7    .480  -146.1
  11.000    .680  -174.1   2.206     8.4    .090   -27.8    .494  -156.0
  12.000    .654   176.1   2.101    -3.4    .090   -35.5    .503  -164.8
  13.000    .638   166.0   2.035   -15.1    .091   -42.6    .514  -173.8
  14.000    .626   157.1   2.003   -26.2    .093   -49.6    .537   178.4
  15.000    .607   147.8   1.975   -37.6    .094   -55.8    .559   171.0
  16.000    .565   138.4   1.917   -50.1    .097   -64.7    .564   162.7
  17.000    .528   127.2   1.924   -62.9    .102   -73.3    .567   154.4
  18.000    .484   112.8   1.966   -77.1    .109   -86.2    .572   142.7
  19.000    .421    93.5   1.932   -91.7    .116   -96.2    .581   113.1
  20.000    .380    74.2   1.991  -107.4    .127  -110.9    .547   124.3
! Noise data 4/90
   2 0.40 .81   32.0 .58
   4 0.50 .74   63.0 .42
   6 0.68 .69   93.0 .30
   8 0.86 .64  127.0 .20
  10 1.03 .60  148.0 .12
  12 1.20 .56  175.0 .08
```

Touchstone File Format (*.SnP)

```
>#    HZ|KHZ|MHZ|GHZ|THZ   G|H|S|Y|Z   MA|DB|RI    [R x]
```

Header Portion
#
HZ | KHZ | MHZ | GHZ | THZ
G | H | S | Y | Z
MA | DB | RI
[R x]

```
! fhx35lg.s2p  4/90
! FHX35LG
! @3V-10mA
! .1GHZ 20GHZ 22
# GHZ S MA R 50
! S-parameter data
   .100    .996    -3.5   4.576   177.2    .002    81.2    .516    -2.5
   .500    .994   -12.1   4.548   169.0    .012    79.3    .517   -10.2
  1.000    .982   -23.5   4.471   158.5    .023    73.1    .513   -19.9
  2.000    .950   -44.7   4.304   139.3    .043    57.9    .498   -38.0
  3.000    .912   -64.6   4.026   121.0    .059    44.6    .483   -54.9
  4.000    .867   -84.0   3.742   103.1    .071    31.8    .462   -71.9
  5.000    .821  -101.6   3.436    86.6    .079    20.0    .446   -87.6
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 11.000    .680  -174.1   2.206     8.4    .090   -27.8    .494  -156.0
 12.000    .654   176.1   2.101    -3.4    .090   -35.5    .503  -164.8
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 15.000    .607   147.8   1.975   -37.6    .094   -55.8    .559   171.0
 16.000    .565   138.4   1.917   -50.1    .097   -64.7    .564   162.7
 17.000    .528   127.2   1.924   -62.9    .102   -73.3    .567   154.4
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 20.000    .380    74.2   1.991  -107.4    .127  -110.9    .547   124.3
! Noise data 4/90
   2 0.40 .81    32.0 .58
   4 0.50 .74    63.0 .42
   6 0.68 .69    93.0 .30
   8 0.86 .64   127.0 .20
  10 1.03 .60   148.0 .12
```

The following are example headers:

```
# GHZ S MA R 50
# MHZ S DB
# HZ Z RI
```

```
Freq NFmindB MagOpt AngOpt Rn
```

where

- `Freq` is the frequency of noise data in frequency units.
- `NFmindB` is the minimum noise figure in dB.
- `MagOpt` is the magnitude of the normalized source gamma to achieve `NFmin`.
- `AngOpt` is the angle (in degrees) of the normalized source gamma to achieve `NFmin`.
- `Rn` is the normalized noise resistance. To have a physical meaning, `Rn` must be greater than or equal to

$$\frac{NFmin - 1}{4 \cdot Re(Yopt)}$$

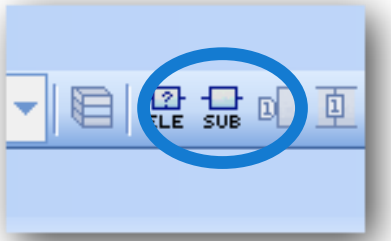
  where `NFmin` is the minimum noise factor (not in dB) and `Yopt` is the optimum source admittance. If `Rn` is less than this minimum it is reset to the minimum.
- `GammaOpt` and `Rn` are normalized to the reference impedance specified in the header for the port parameter data (usually 50 ohms).

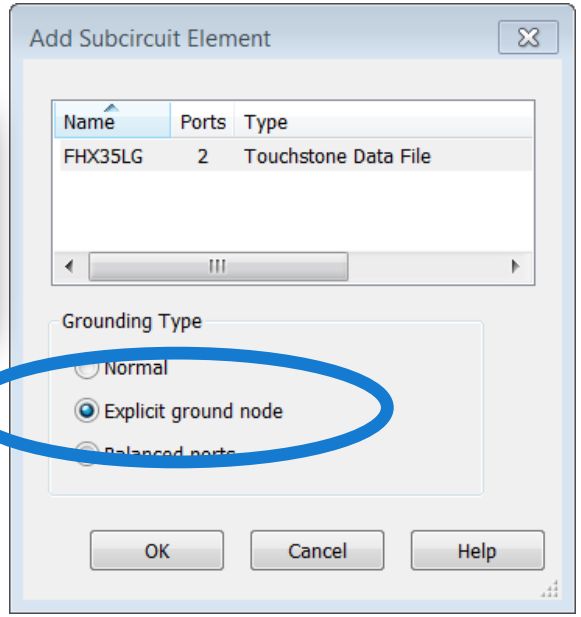
Subcircuits and S Parameters

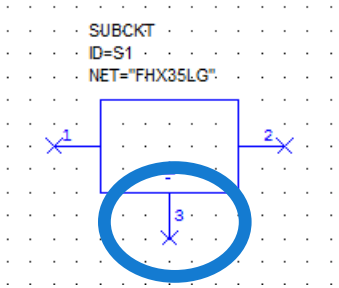
Step 4: Insert the data set as a subcircuit into the schematic “Device”.

Note: You can insert a subcircuit by:

- Draw - Add Subcircuit
- Click on the Icon
- Hotkey is: Ctrl-K



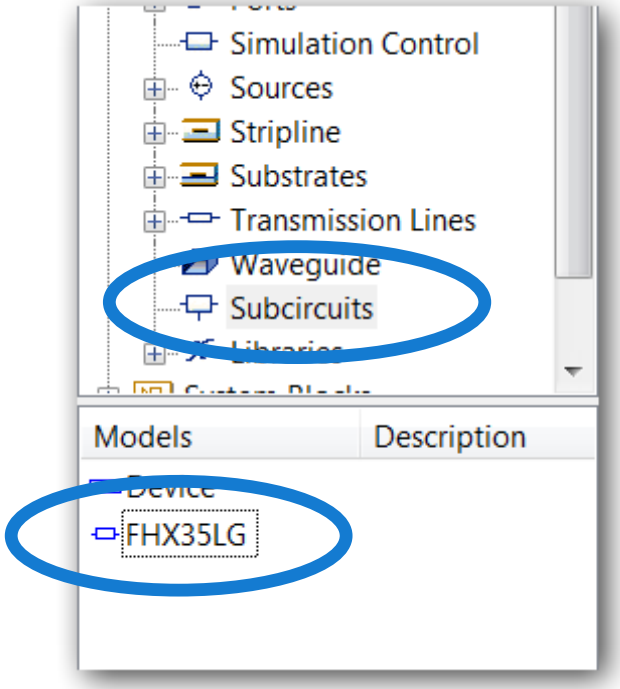




Make sure you select Explicit Ground Node. This is used for transistor S parameter data - so you expose the 3rd port (Usually the source in common source.) For interconnect S parameter data - use Normal.

Another Way to Bring in a Subcircuit

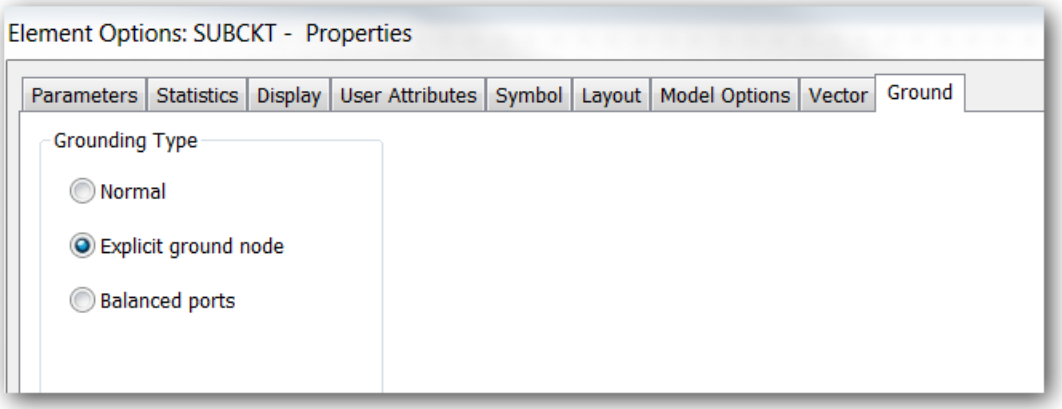
You can also bring it into the schematic by going to the Elements Browser - Subcircuits



And then drag it into the schematic.

To expose the ground node – you must right click on the subcircuit in the schematic => Properties.

Then – change it under the ground tab.



Exposing the Ground Node

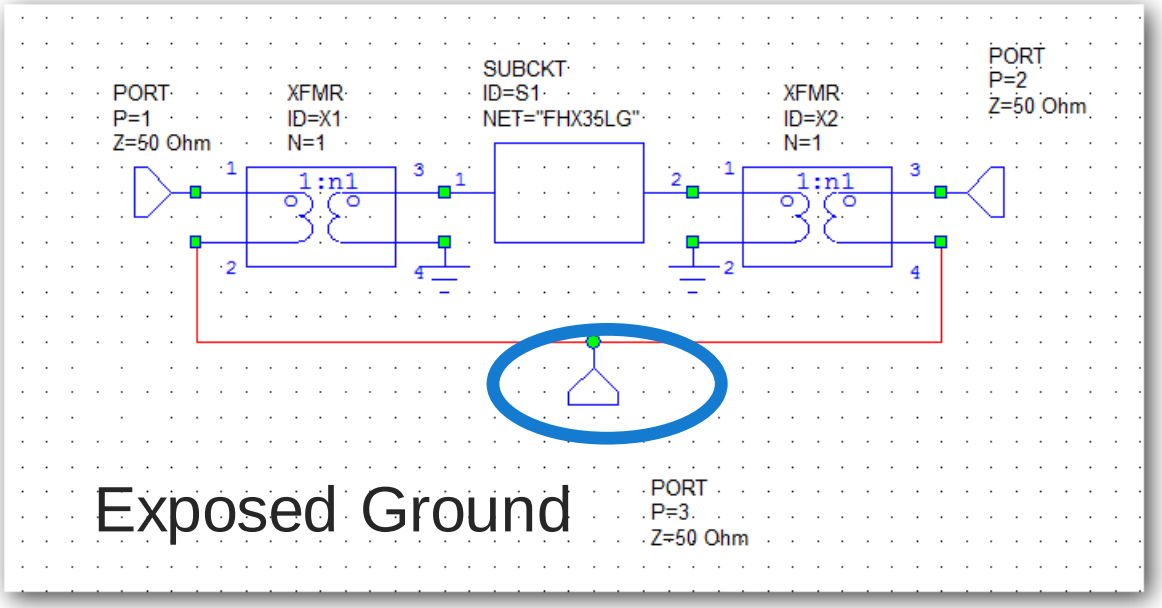
This adds a third node – the “ground” of the transistor. You can now connect circuit elements to it.

Physically – it is valid to do this if all the ports in the subcircuit have the same ground – which they should for a device file.

Conceptually – it does this.

Details are in the built in example –

Exposed_Ground_Node.emp

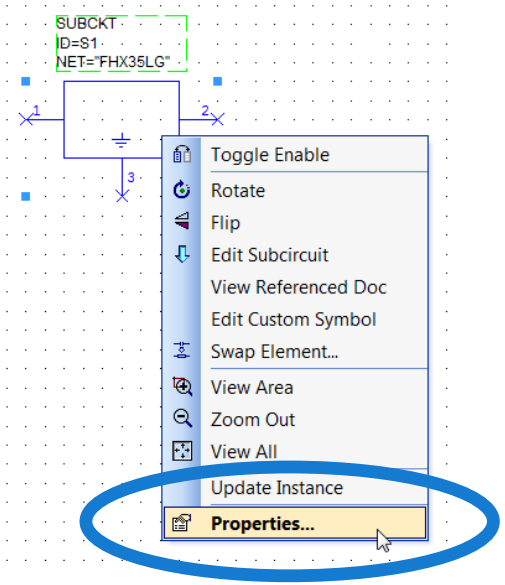


Changing Symbols

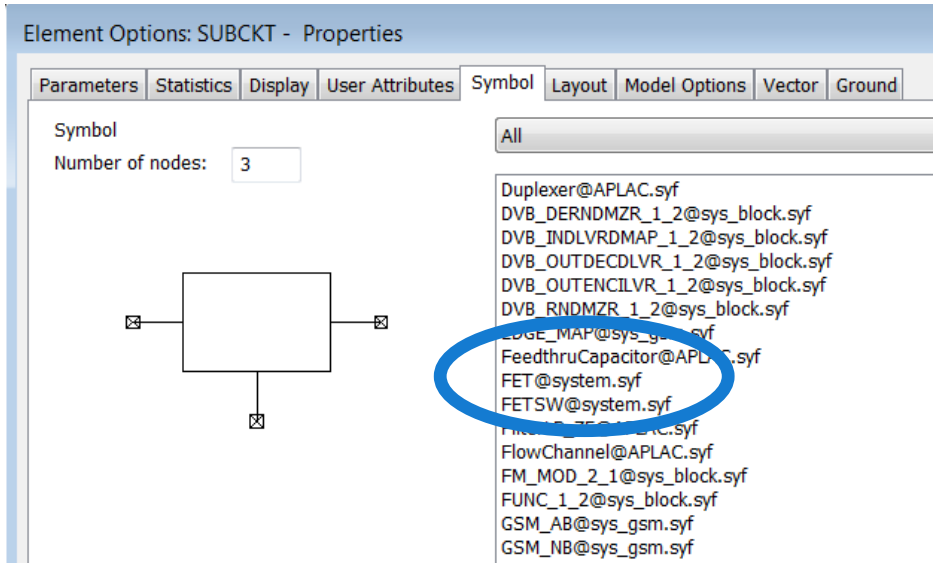
Step 5: Change the Symbol to a FET.

It looks more like a transistor and is less confusing which port is which.

Right Click (RC)



Select the Sub-Circuit's Properties



Select the FET symbol

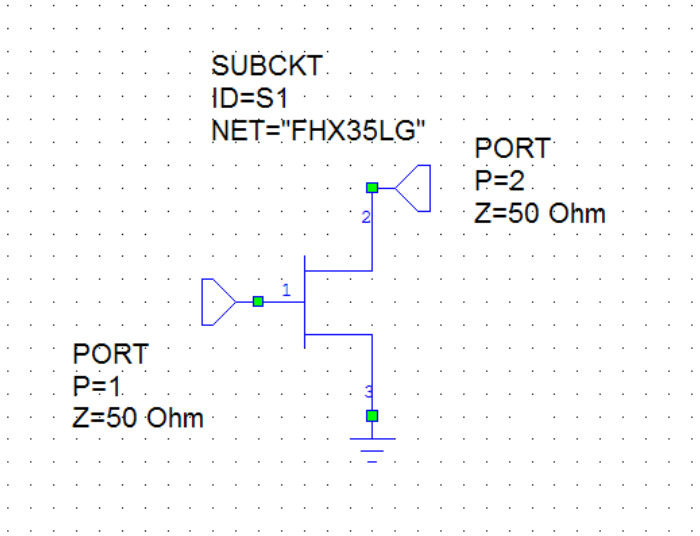
Tip: Make sure the port numbers of the symbol - match what you expect.

Complete the Schematic

Step 6: Complete the amplifier by attaching ports.

Tip: Useful Hot Keys:

- Add a port: Ctrl P
- Add a ground: Ctrl G

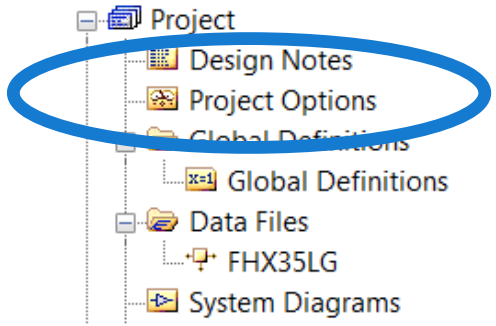


You can rotate, flip, and mirror the port before placing it.

- To rotate - right click (RC)
- To Flip About the Horizontal Axis - Shift RC.
- To Flip About the Vertical Axis - Alt Shift RC.

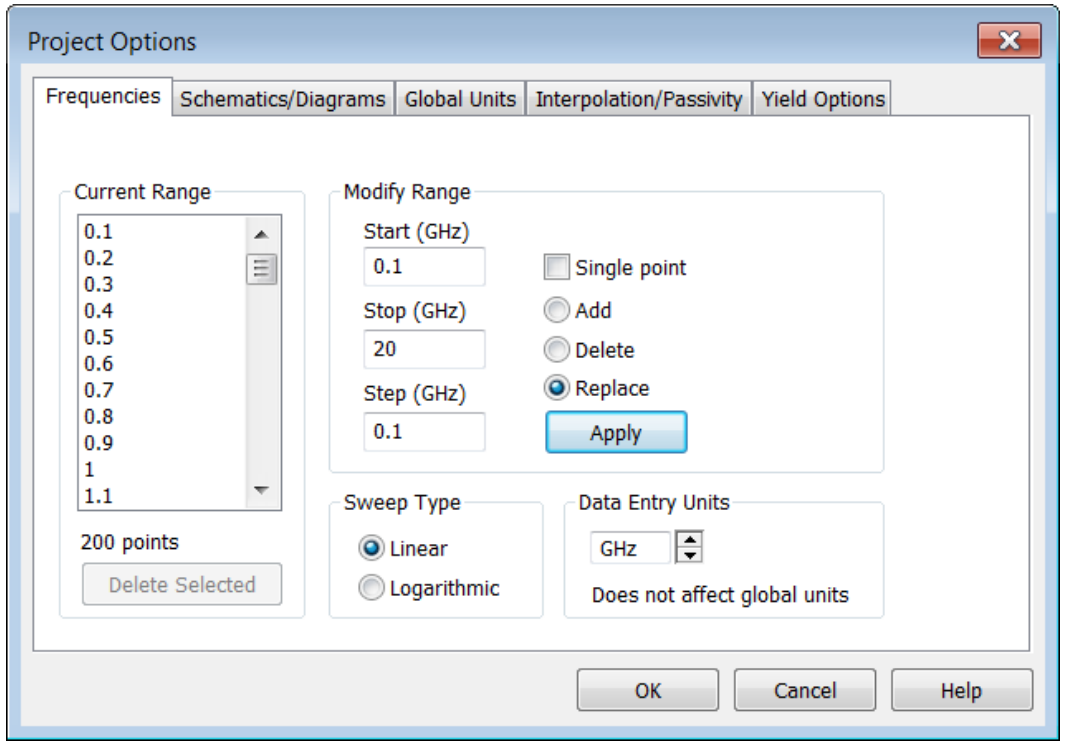
Set the Frequencies

Step 7: Set the simulation frequencies from 0.1 to 20 GHz - in steps of 0.1 GHz.



Double-click Project Options

Tip: This sets the frequencies for all project simulations - unless you override them. You can do so at the individual circuit level, or EM simulation level.

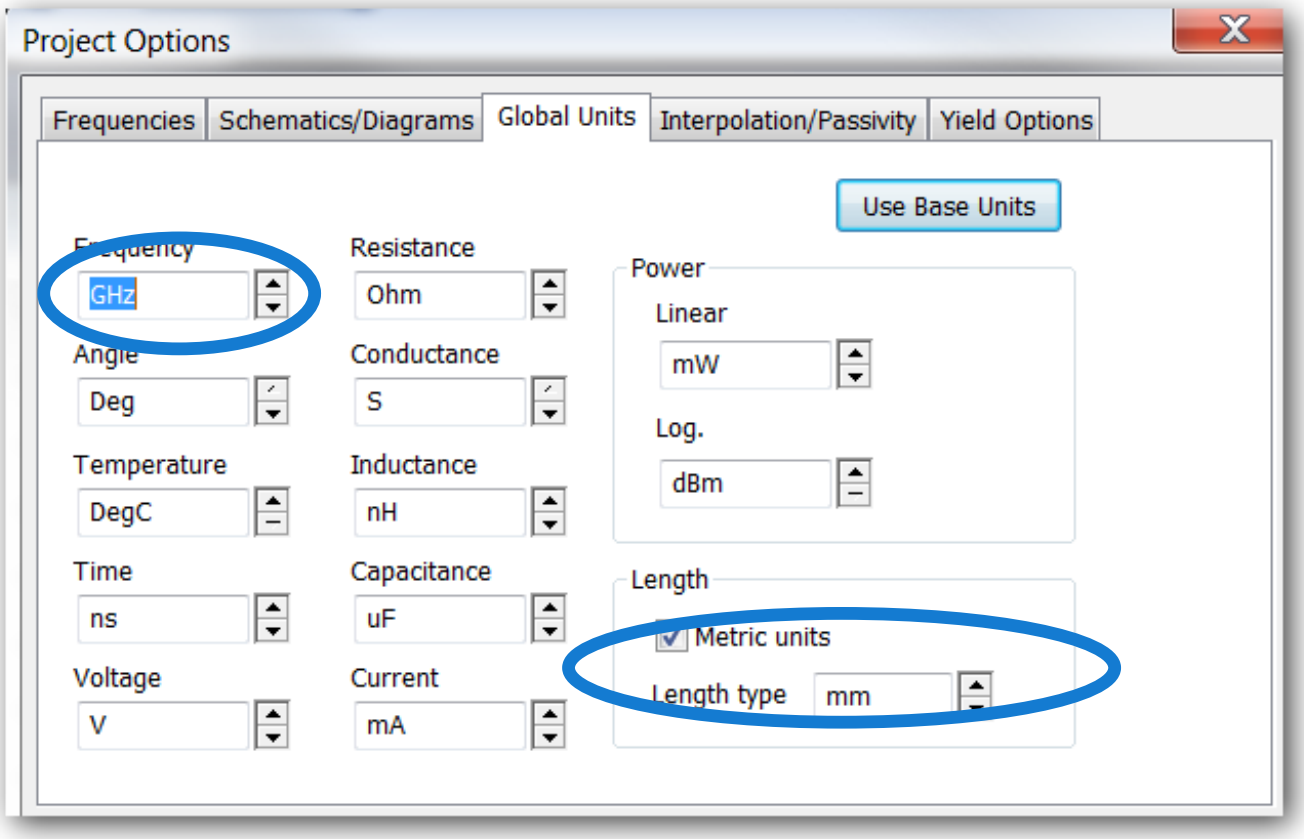


Use the Apply button to check bandwidth and frequency points and see them in the left window.

But – the OK button will set them too.

Set the Units

Go to the Global Units Tab of the Project Options Dialog Box.



Set frequency to GHz and length to mm.

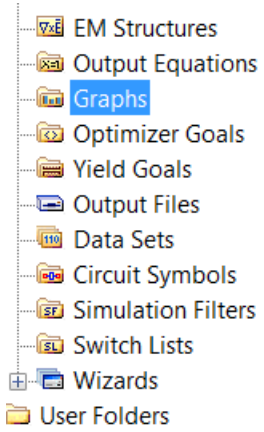
Tip: It's not a good idea to change your units in the middle of creating a design.

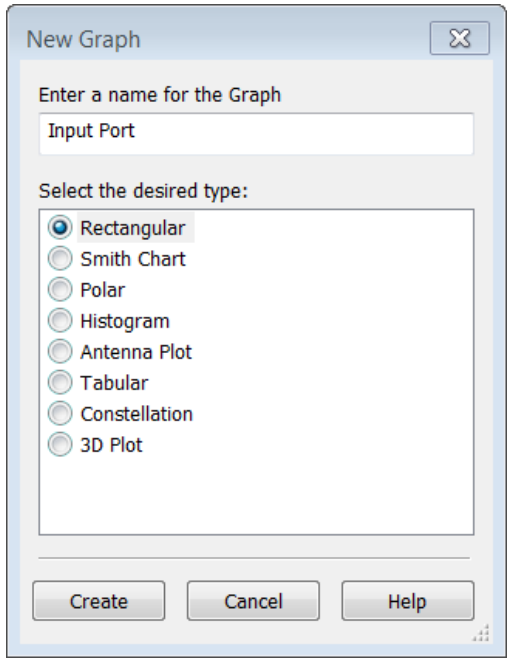
Creating Graphs

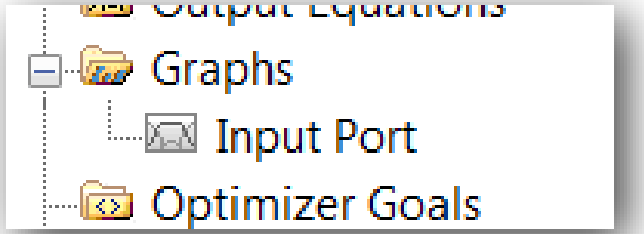
Step 8: Create the Graphs and Measurements

Create a rectangular Graph by:

- Right Click on Graphs in the Browser.
- Type in the name – Input Port
- Make it a rectangular graph.





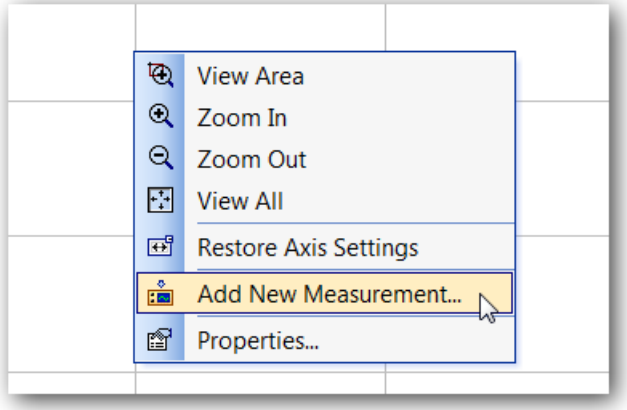


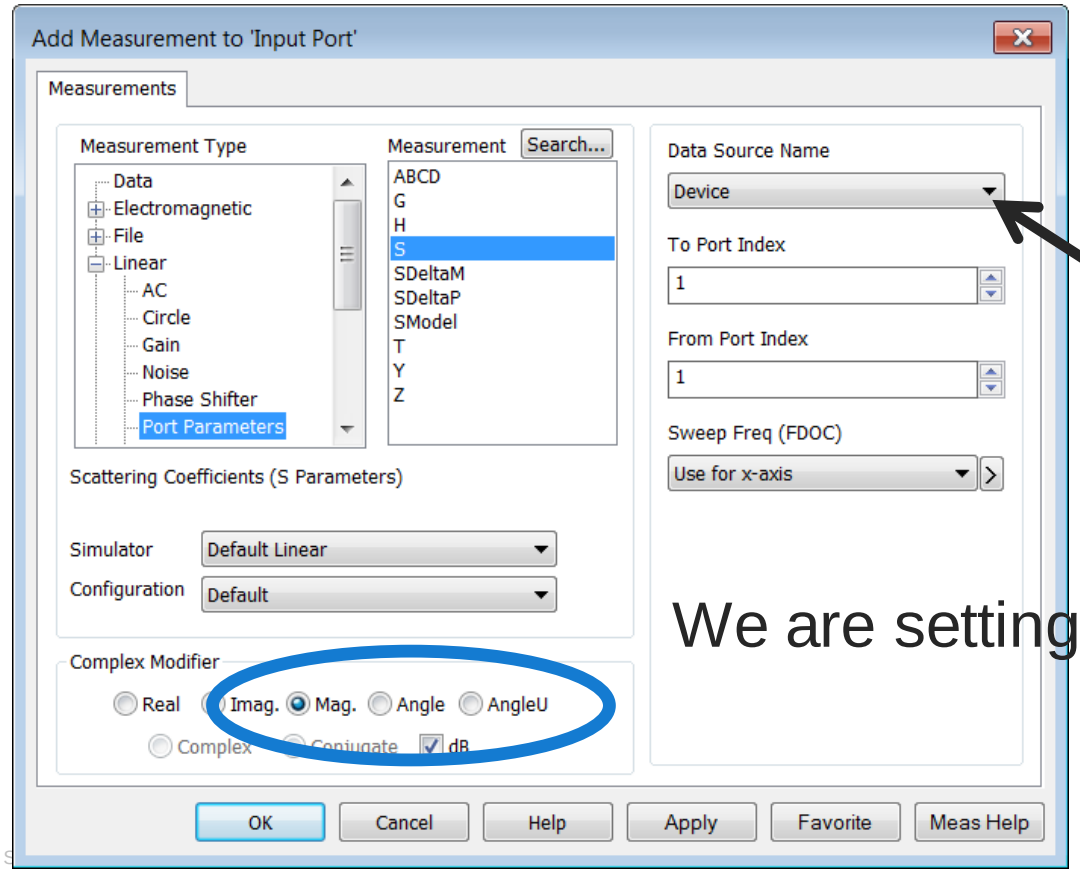
Tip: Spaces are fine in schematic and graph names. Avoid them for other things.

Creating the Measurement

Right click on the empty graph – Add New Measurement.

This has all the built in measurements in the software.

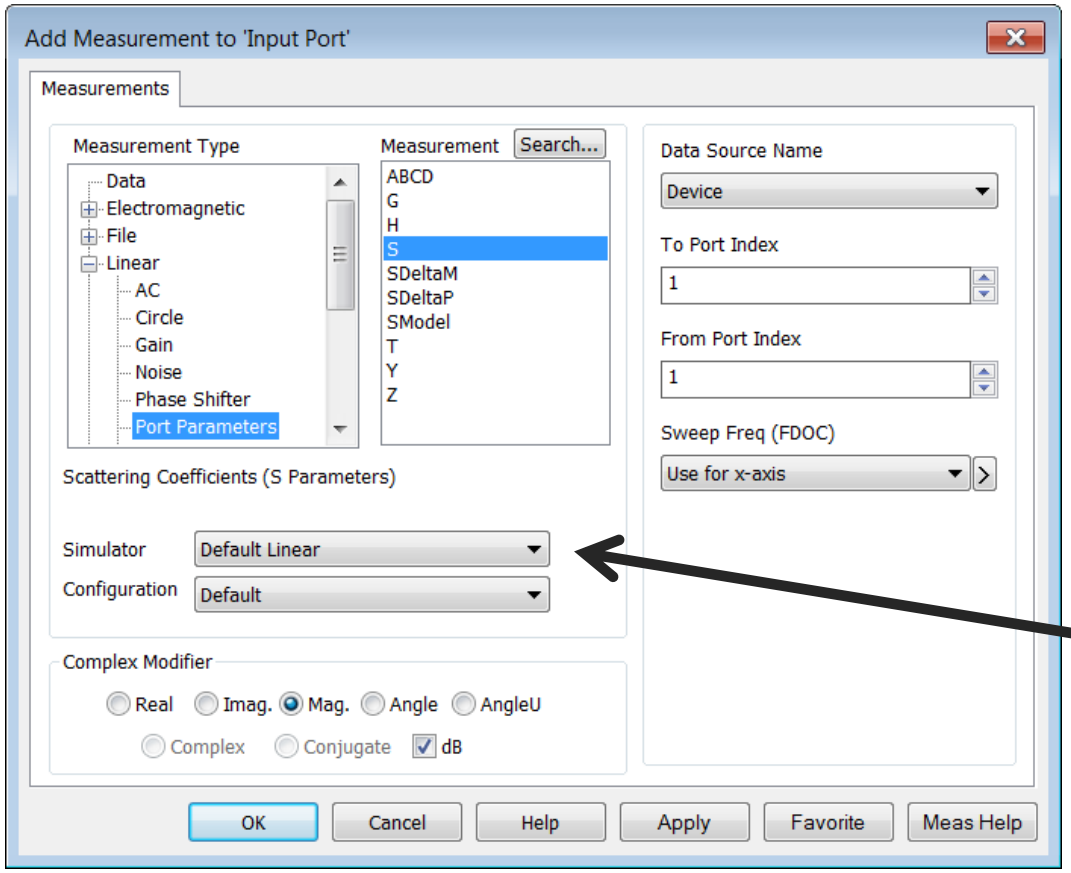




Data Source is the schematic or data file.

We are setting Magnitude dB.

The Measurement Dialog Box



Microwave Office is very measurement centric.

It doesn't use the schematic for a lot of control.

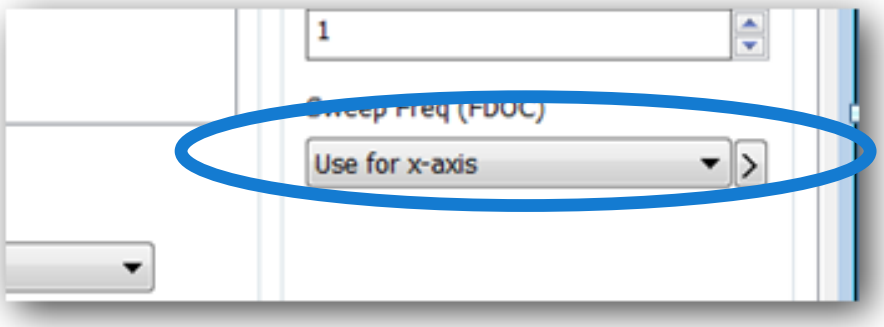
For example -

You set the simulator type here-

Linear, Harmonic Balance, …

The Swept Frequency and the X Axis

All graphs (even tables and Smith charts) assume something is sweeping. Usually the swept variable is frequency, but we can also sweep – length, impedances, etc.



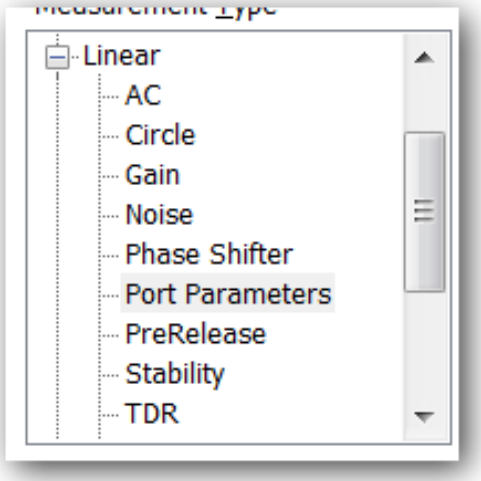
The swept variables get boxes.

One and only one of them – gets “Use for x-axis”.

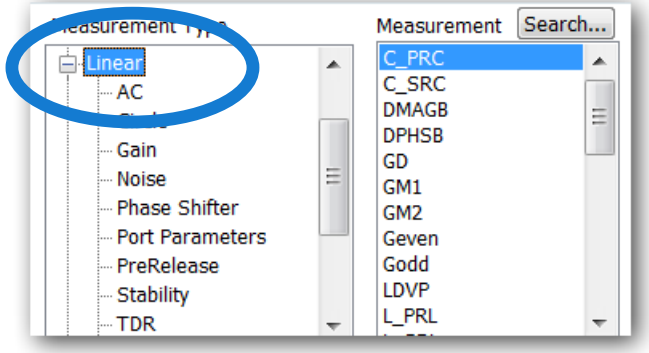
Even a Smith chart and a table need this. Think of the “use for x-axis” as a special sweep variable in the graph.

Example – for a table, it is the variable going vertically downward in the table.

The Types of Linear Measurements



- Port Parameters – S, Y, Z, …
- Circle – NF circles, Stability circles, …
- Gain – the standard gain measurements
- Linear Noise and Stability Measurements
- TDR – A step or impulse response from the S parameters.

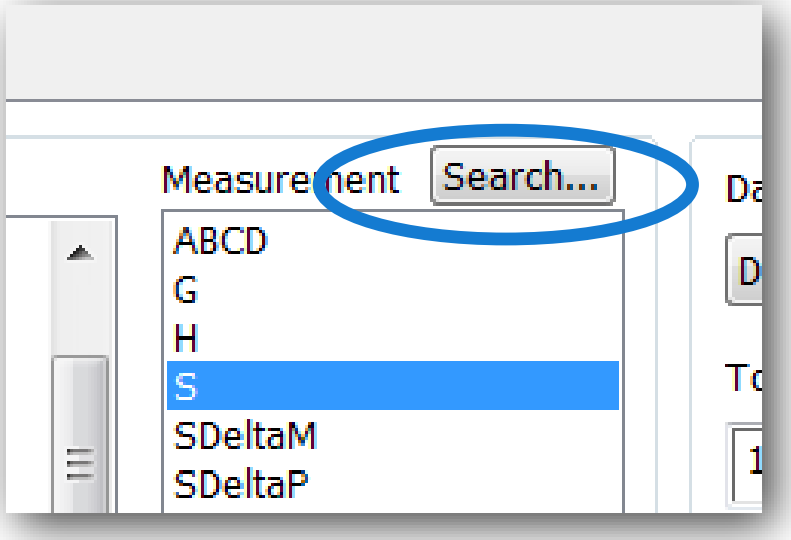


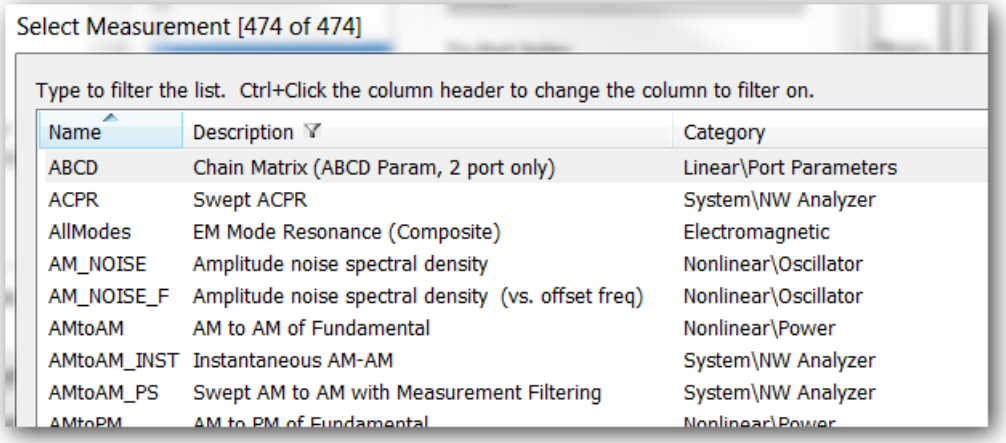
Tip: Right under Linear are measurements are many measurements, including:

- Input Impedance
- Values of R, L ,C of simple topologies,

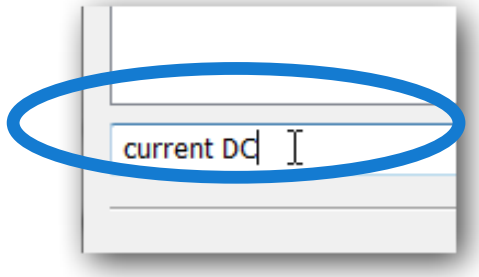
Help on Measurements

You can search for measurements in the dialog box …





Use Ctrl + click at top of column to change search for name or keywords.

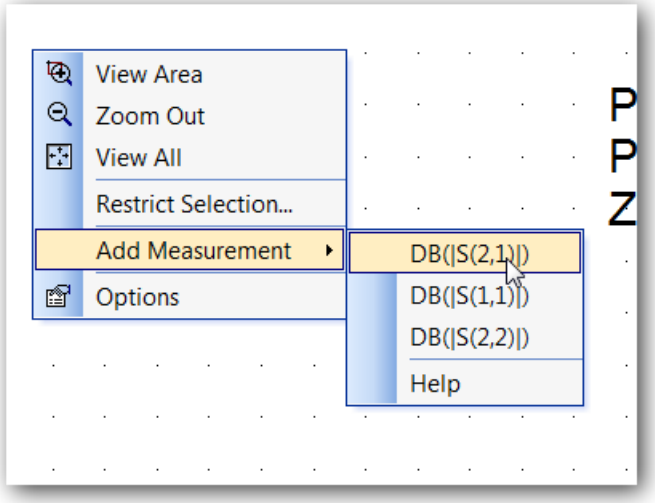


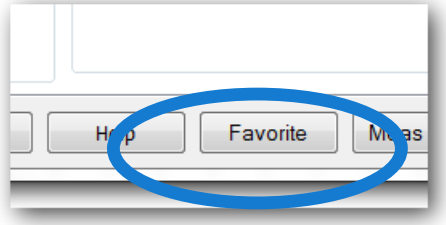
You can type in keywords at the bottom.

Favorite Measurements

Favorite measurements allow you to pick measurements on a schematic.

- In the measurement dialog box – click on Favorite.
- In a schematic – right click and you can use the measurements.

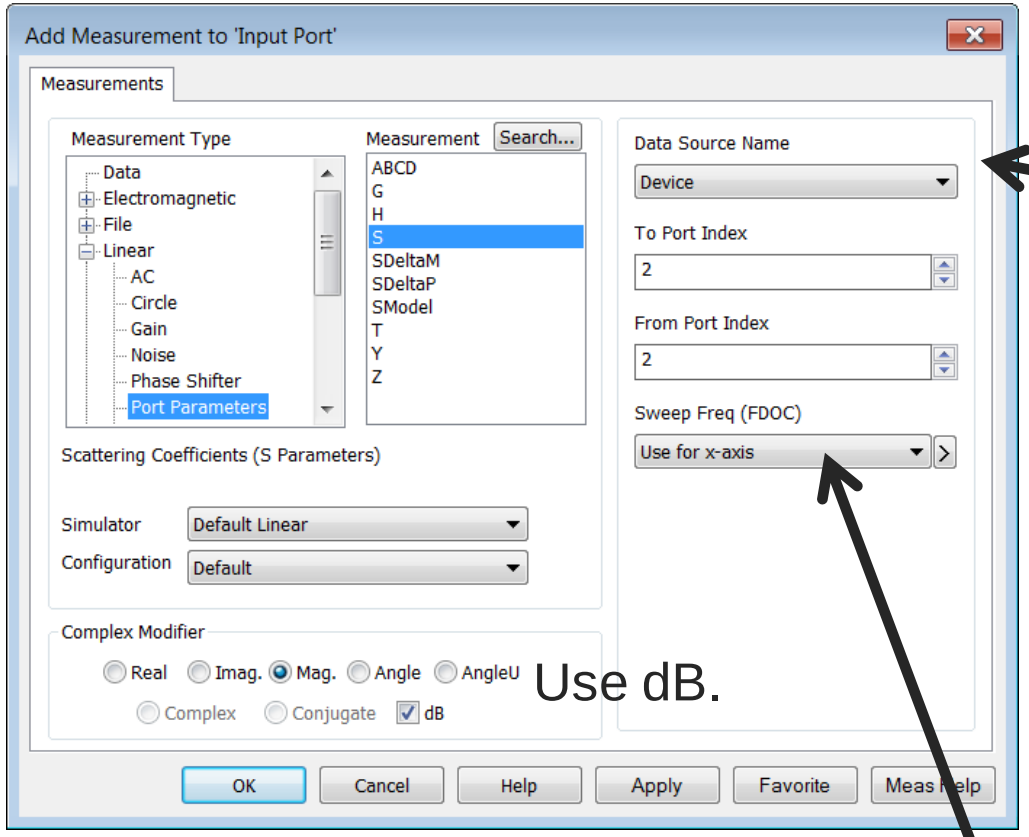




Tip: Normally – after clicking, you are asked for the graph you want, and the measurement dialog box appears. You can skip these with Ctrl and Shift.

Add S22

Add a measurement S22 to the same Graph.



Data source name

Use dB.

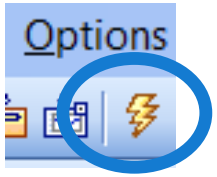
We are sweeping the x - axis with Frequency

Running the Simulator

Step 9: Run the simulator.

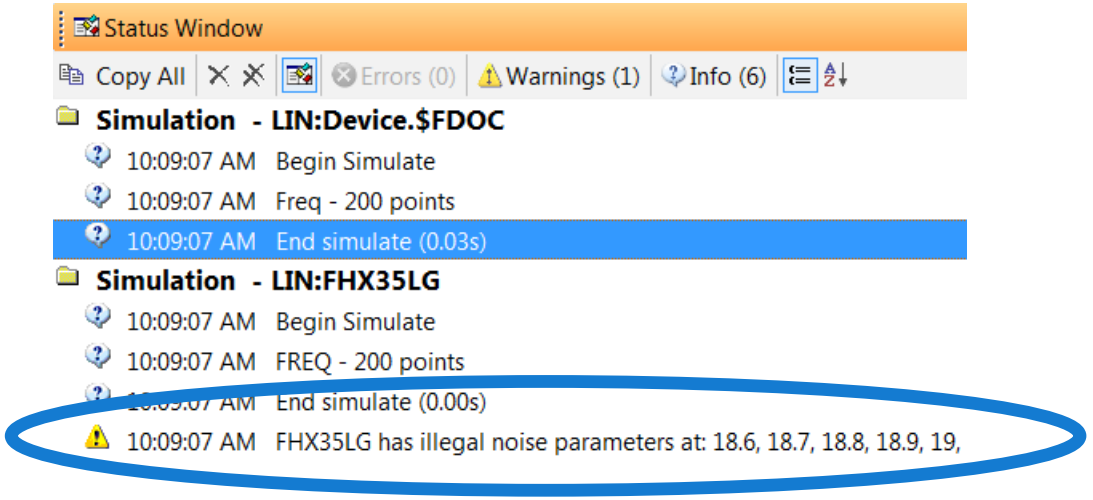
Three ways to do this:

- Lightning Bolt in the Toolbar icon
- Simulate > Analyze
- F8 – the default hotkey.



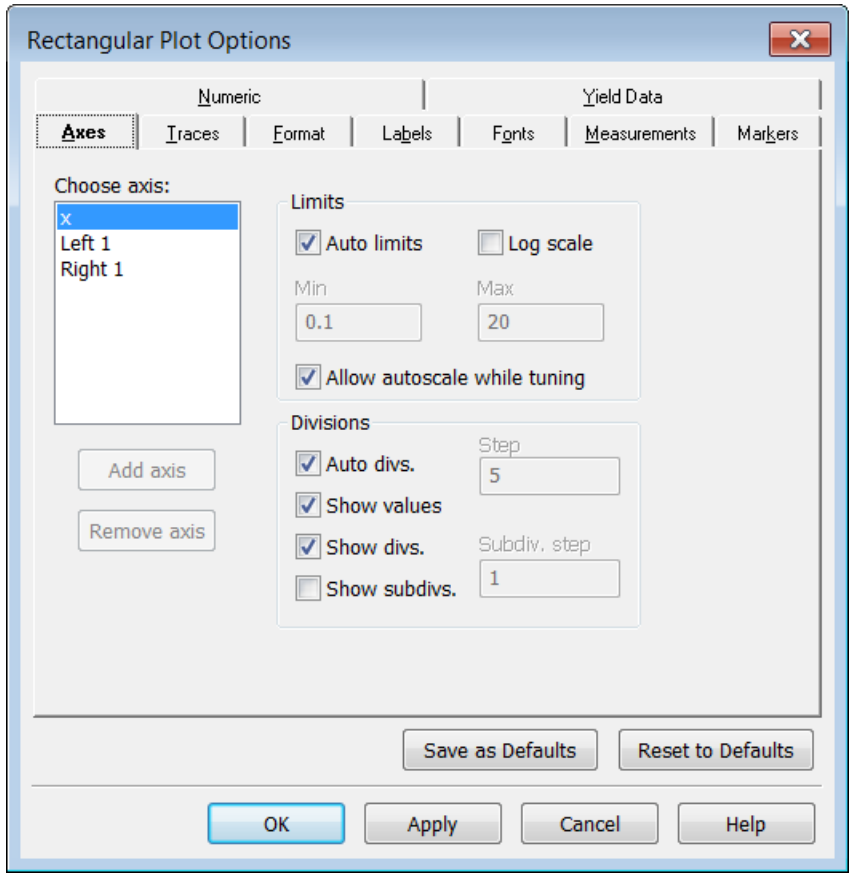
Standard Toolbar

You will get a warning message. You don't have any noise data at 20 GHz - so it is extrapolating.



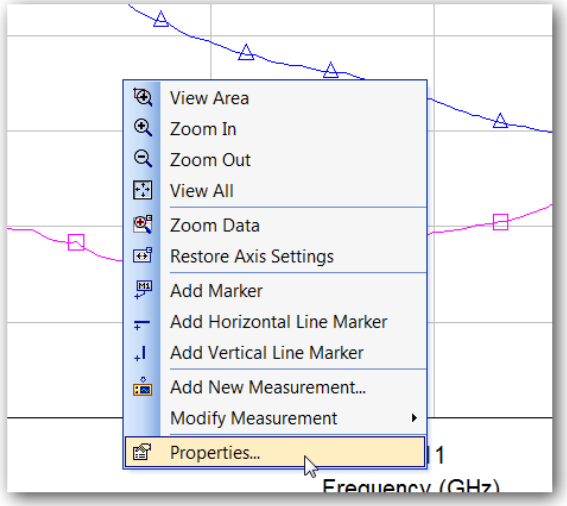
Tip: Pay attention to warning messages – they are there for a reason.

Changing the Graph Properties



You can change the appearance of the graph in many ways.

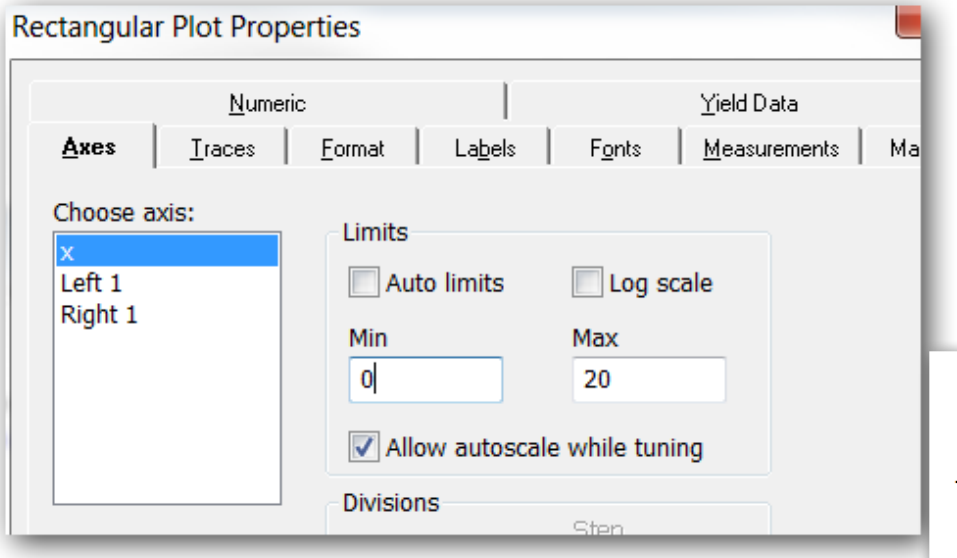
Right Click in the graph window > Properties.



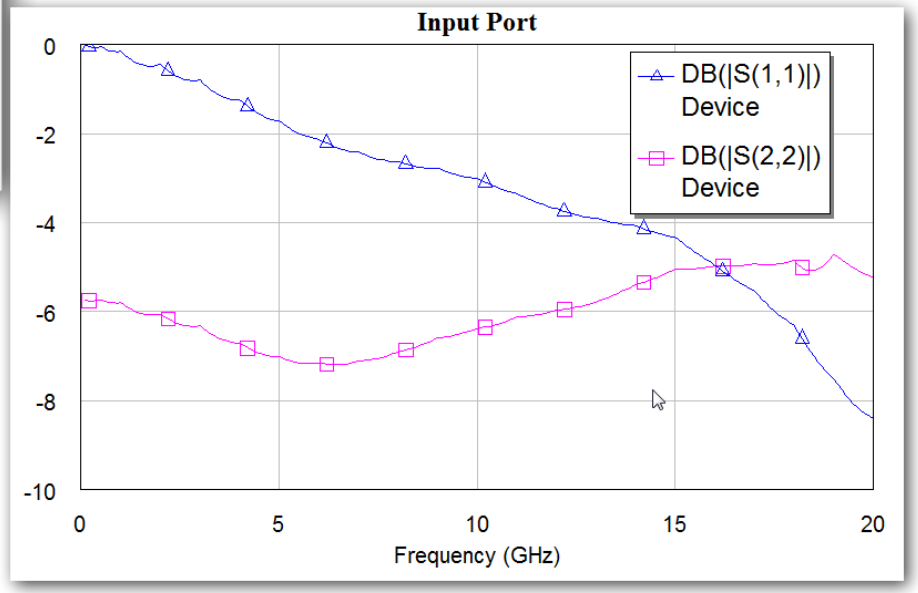
Tip: You can also get to this menu by double clicking the legend of the graph.

Axes Properties

Autoscaling is turned on for the X and Y axis by default.



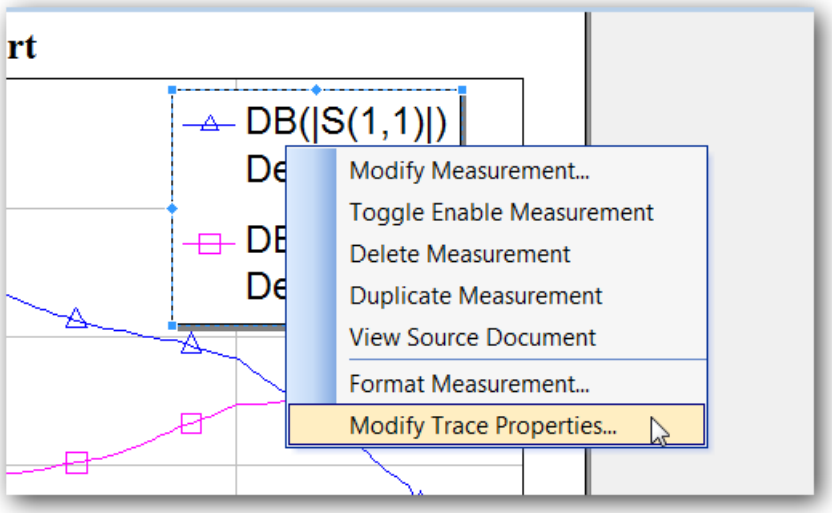
Turn it off for the X axis and set the minimum frequency to 0.

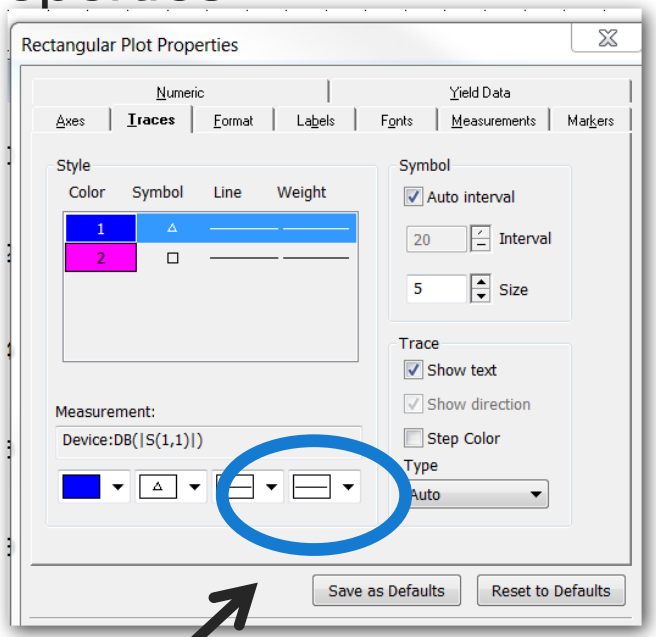


Trace Properties

They are under the Trace tab of the Graph menu.

You can get to them directly by right clicking on the trace in the legend > Modify Trace Properties.





Make the traces thicker.

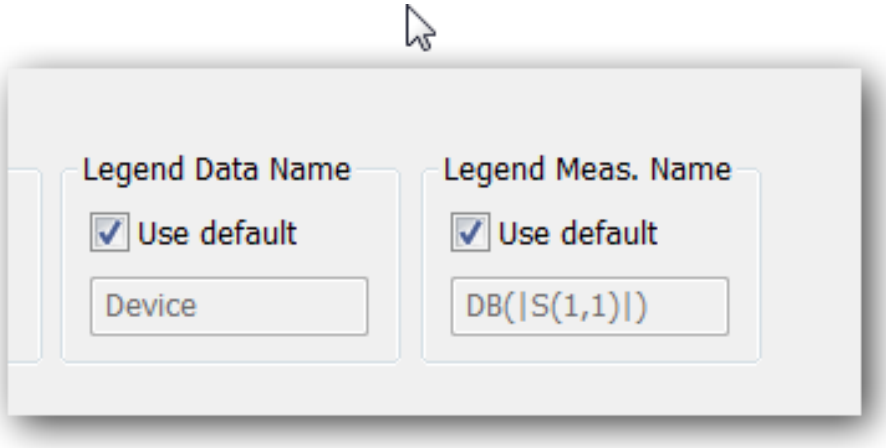
You can change – color, type, etc.

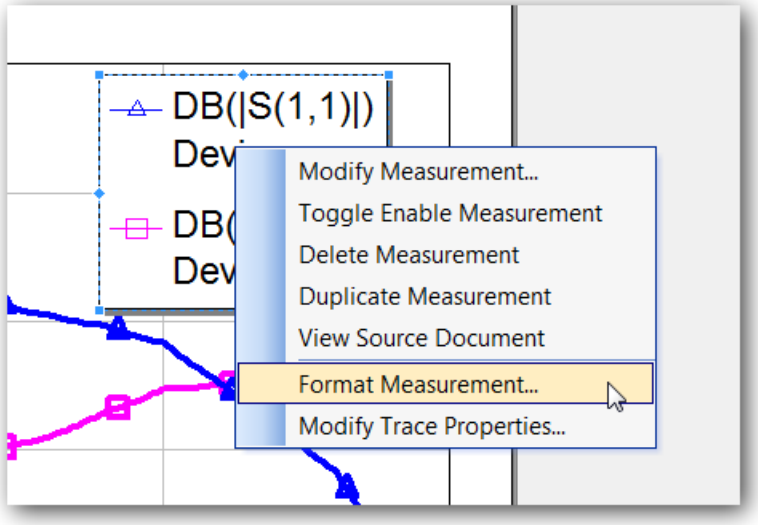
Modifying the Legend

You can change the legend if you wish.

Under the Measurements tab …

You can get to it by right clicking on the measurement in the legend > Format Measurement.

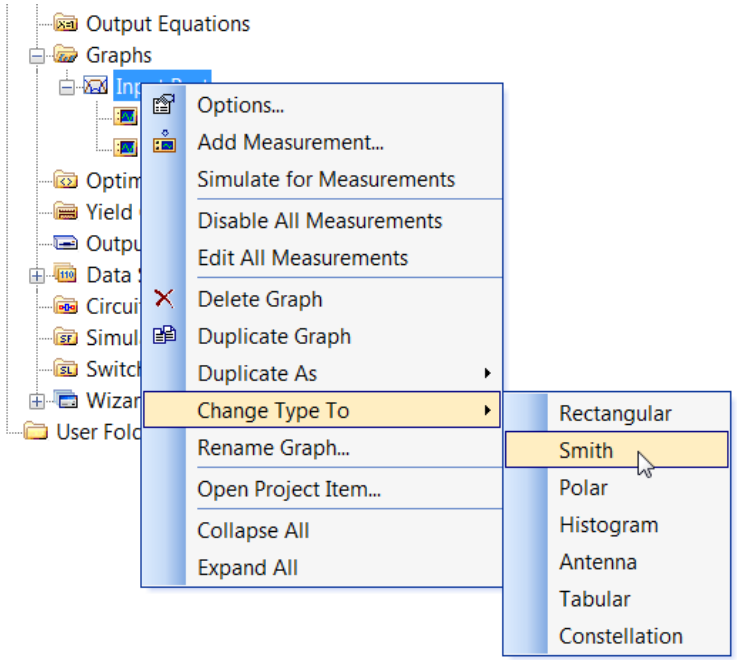


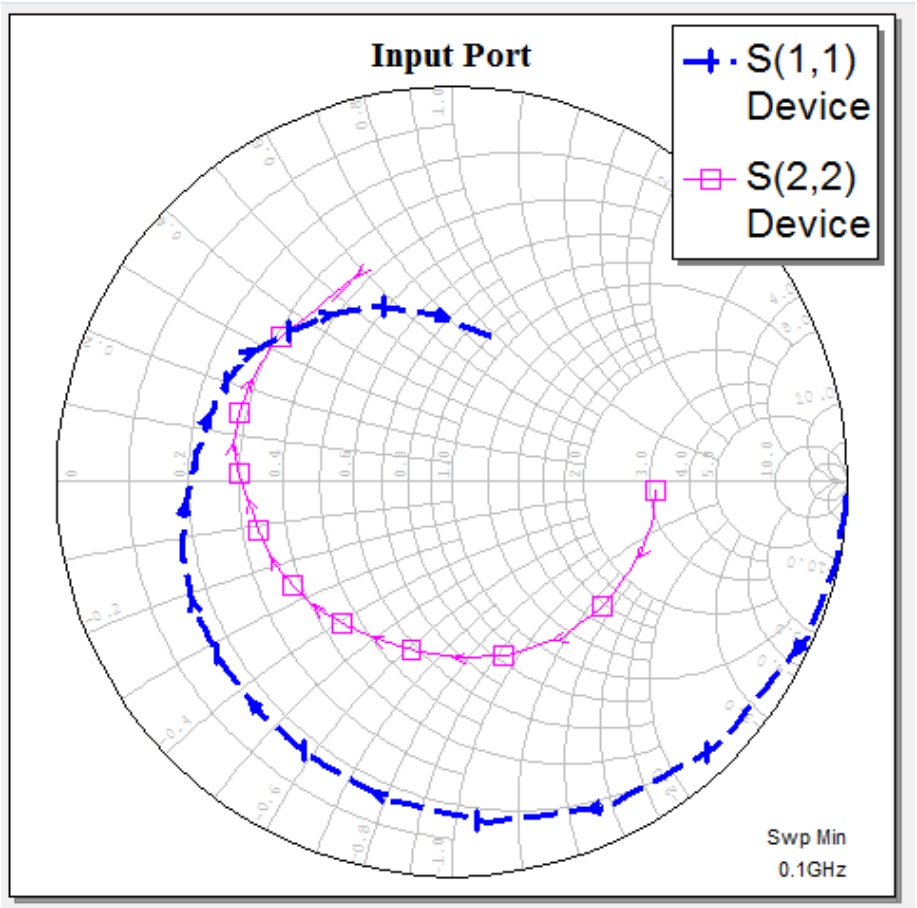


You can change the data name and measurement names if you wish.

Change the Graph to a Smith Chart

Step 10: Change the graph to a Smith Chart.





Right Click on the graph in the Browser > Change Type to > Smith.

Simulate – to refresh the chart.

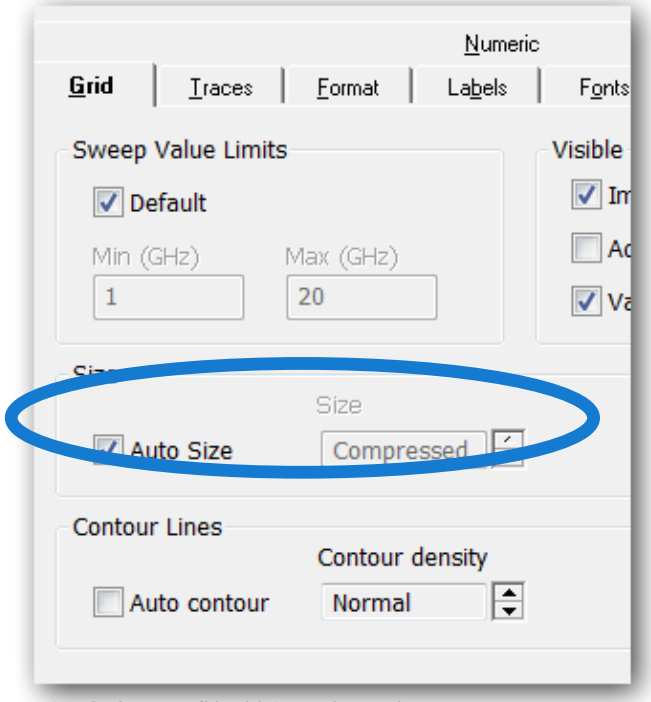
Add S21 to the Smith Chart

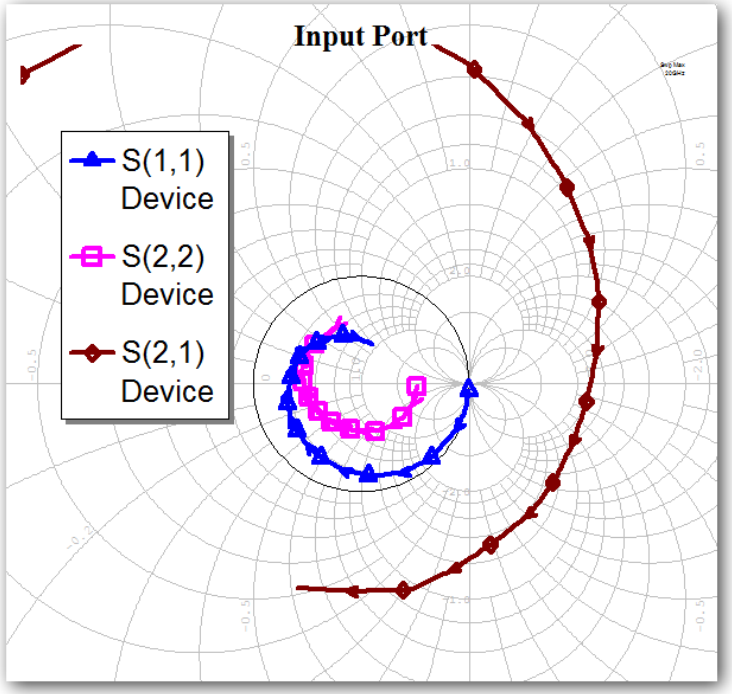
Add the measurement S21 to the Smith chart.

To see it – you have to expand the chart.

Go to the graph properties – the grid tab.

Click on Auto Size.





There is gain.

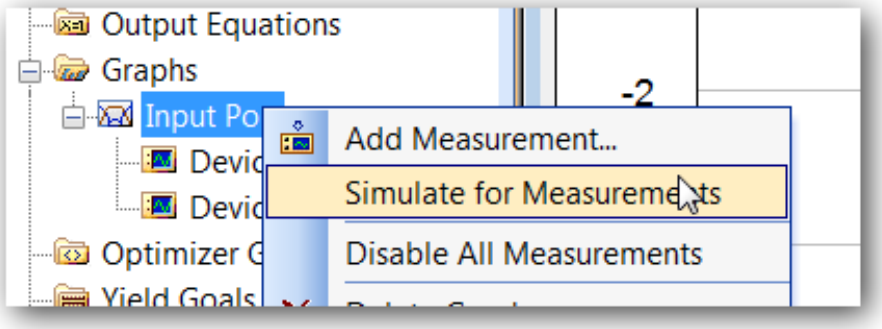
What Simulation Really Does

When you “simulate” –

- It looks at all measurements on all graphs.
- Any measurement that is “stale” has its trace grayed out. It could be because:
  - The schematic or data file has changed. Re-simulation is required.
  - Frequencies changed. Re-simulation is required.
  - The graph type changed: Ex – rectangular > Smith, or Axes changed. No re-simulation required – just re-plots it.
- It will simulate any EM projects – even if they don’t have a measurement pointing to them – unless they are up to date.

You Can Simulate / Update Only Part of the Measurements

In the Project Browser – you can right click on a graph or a measurement and only simulate it.



Only simulates / updates what is necessary for the measurements on this graph.

Tip: This can save you a lot of time when you have complicated project with several graphs, and don't want to run lengthy simulations (usually nonlinear) that you don't need.

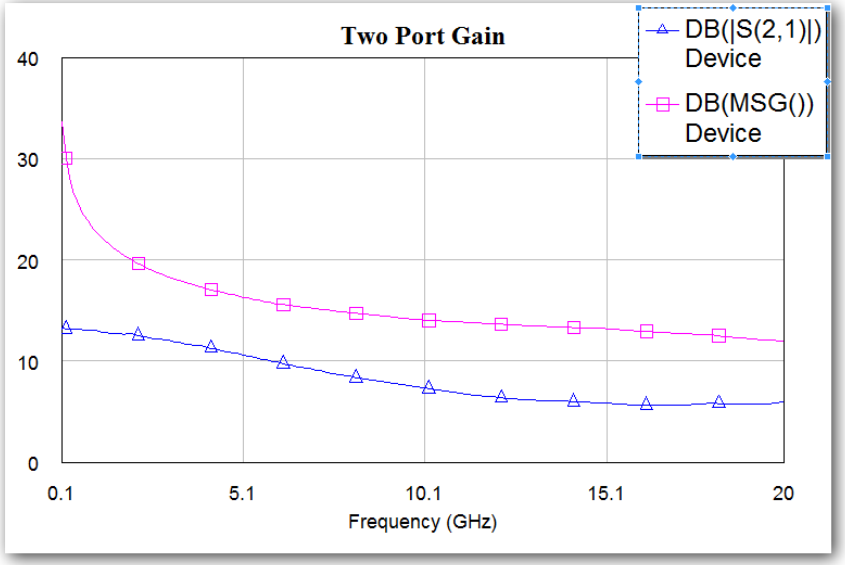
Look at the Gain

Step 11: Add a rectangular graph - “Two Port Gain”.

-Add measurement: S21 (Measurement type Linear > Port Parameters)

-Add measurement: Maximum Stable Gain (MSG) (Measurement Type - Linear > Gain)

Use dB for both measurements.

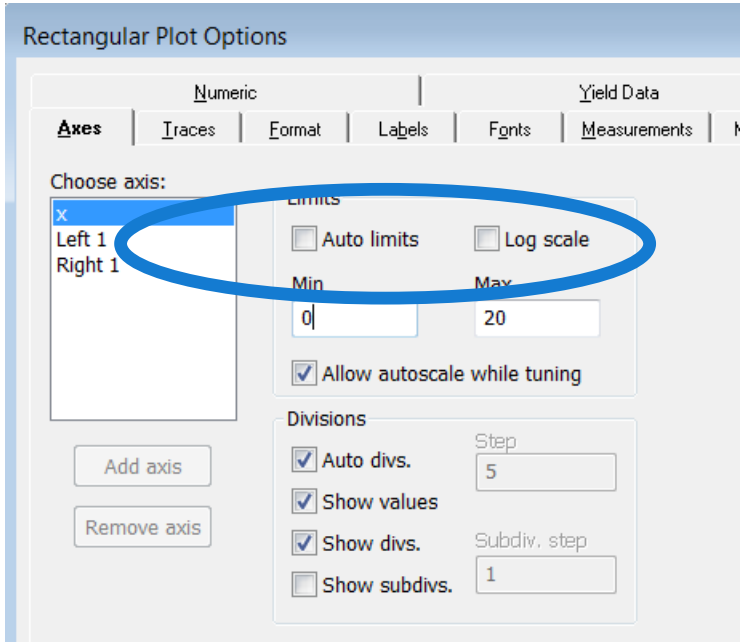


Make the Graph Look Nicer – Change the X Axis Limits

Step 12: Make the Graph Look Nicer.

RC on the Graph > Options

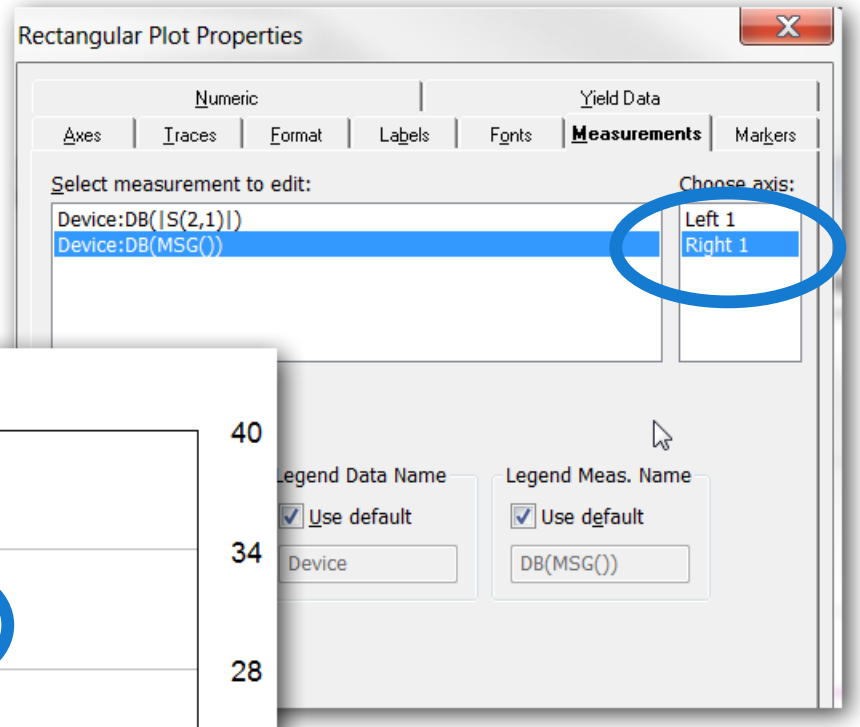
Change the x axis limits to 0 to 20 GHz.

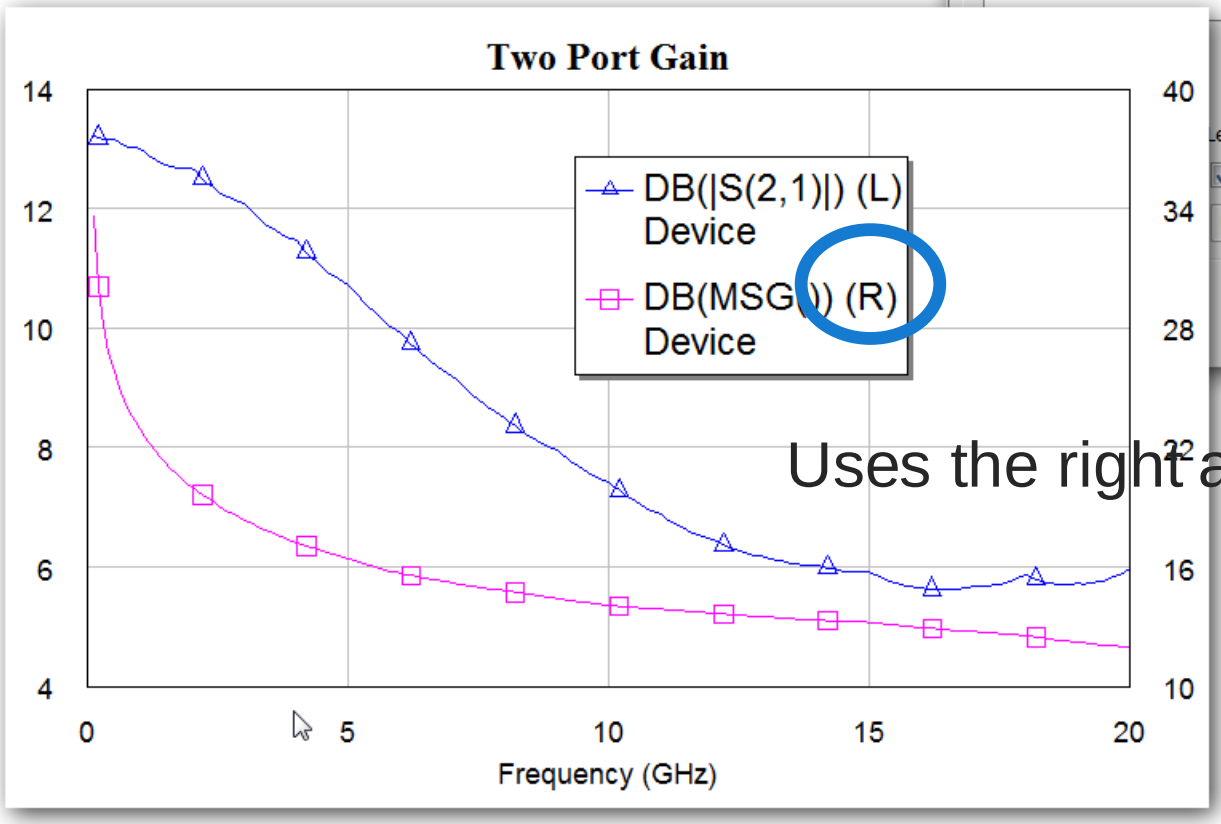


We will use the left axis for S21 and the right axis for MSG.

Use the Right Axis for the MSG Measurement

Under the Measurement Tab – Set the MSG Measurement to the right axis.





Uses the right axis.

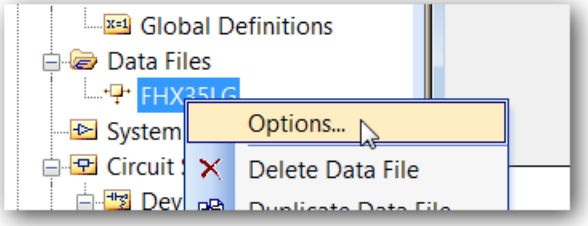
A Note on Interpolation

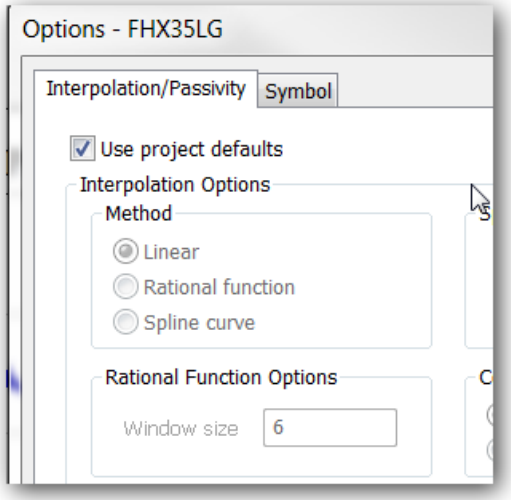
The source of our measurements is the Device schematic.

It uses the S parameter data file – FHX35LG.s2p.

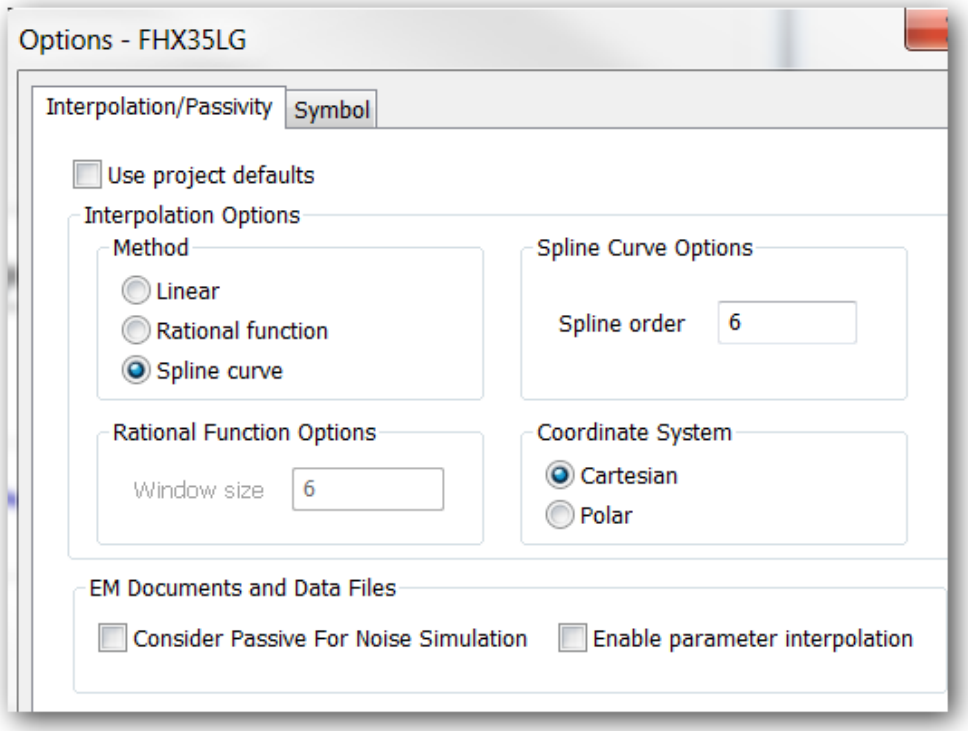
If we use frequencies not in the data file, it must interpolate the data.

We can change how the interpolation is carried out by right clicking on the data file in the browser > Options.





Interpolation



The methods are:

- Linear – straight line between points (the default)
- Rational – smooth curve created by pole/zero algorithm.
- Spline – smooth curve created by splines.

For more info - look at Interpolation_Example.emp

Change it to Spline order 6 – the curve gets smoother.

Tip: If you used FHX35LG.s2p as the data source of the graph – it always uses linear between the data points. No schematic is using the data set.

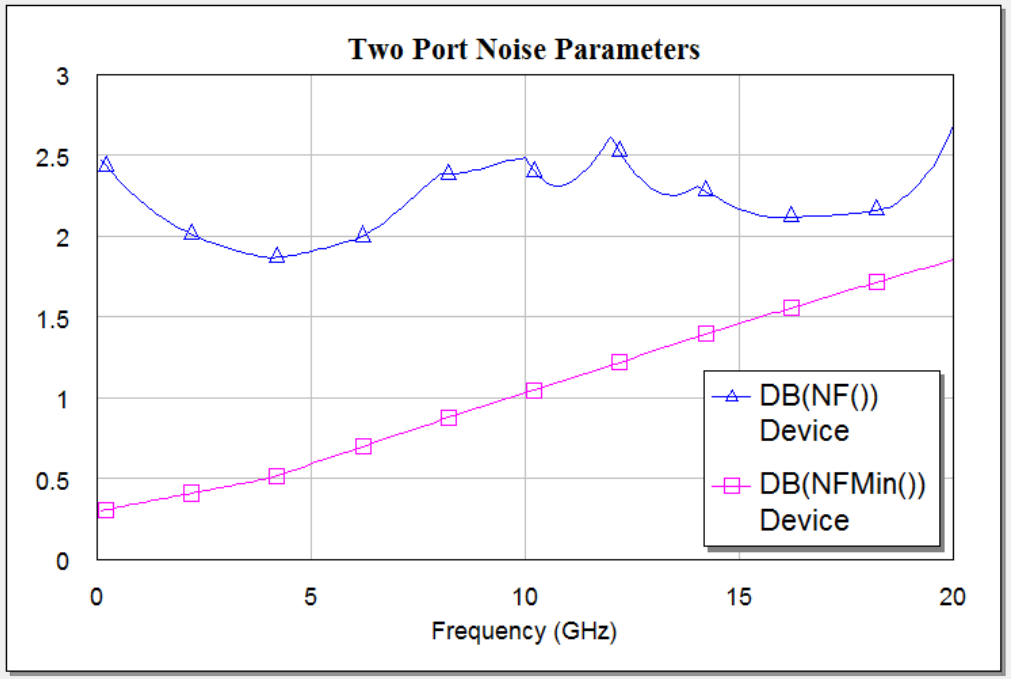
Linear Noise Measurements

Step 13: Make a Rectangular Graph “ Two Port Noise Parameters”

-Add measurements for Noise Figure (NF) and Noise Figure Minimum (NFmin)

-Use dB.

(The measurement type is Noise.)

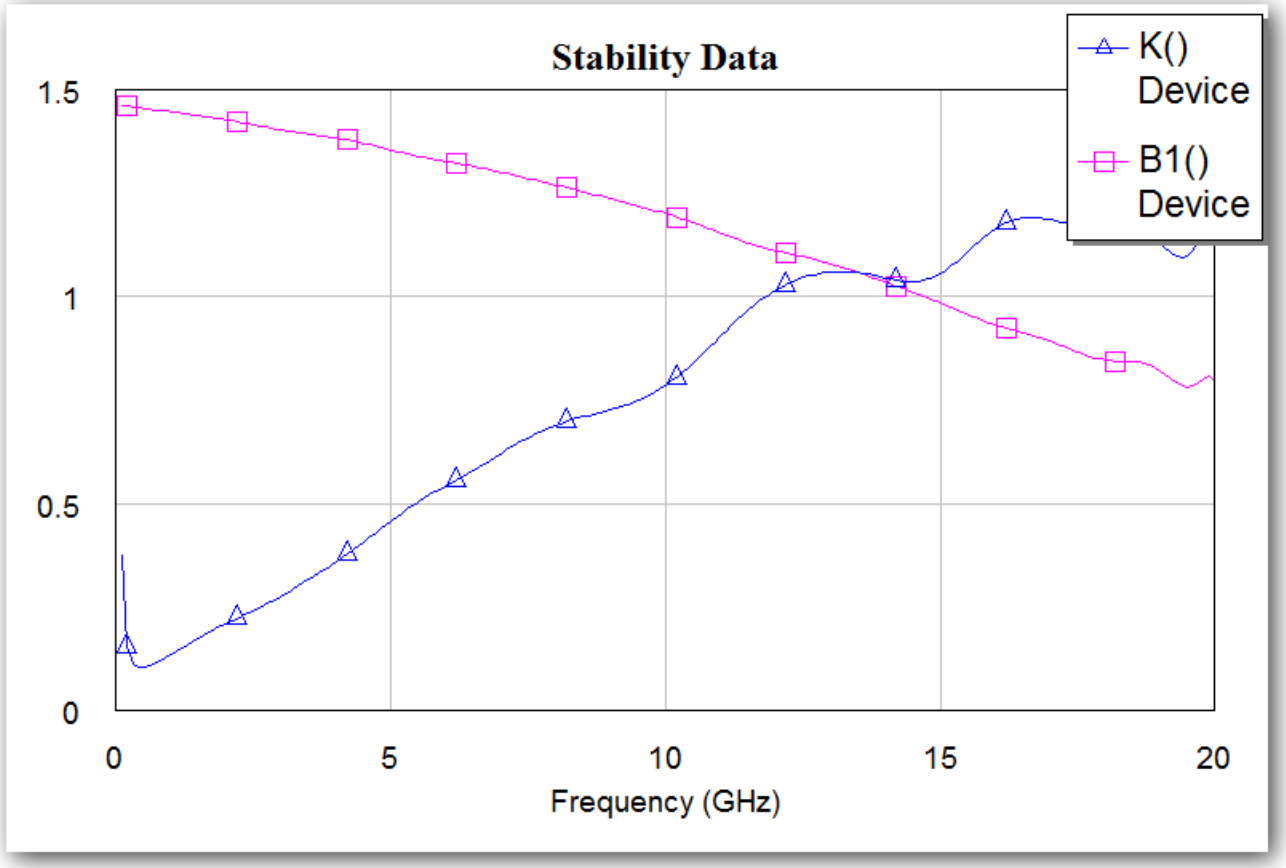


Set the X axis to go from 0 to 20 GHz.

The Stability Factors K and B1

Step 14: Create a graph “Stability Data”

- Add measurements for K and B1. (Measurement type is - Stability.)



Note: Don’t use dB.

If K < 1 or B1 < 0, the circuit is not necessarily stable.

X axis has been changed to be 0 to 20 GHz.

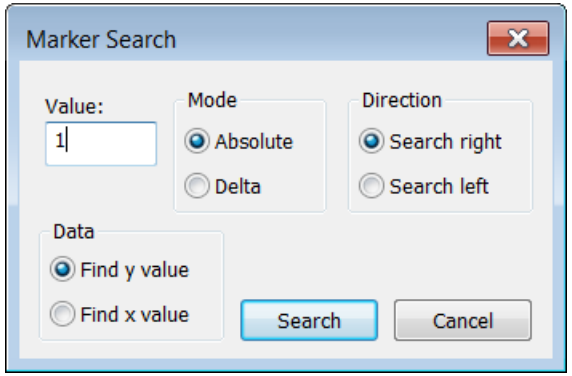
Adding Markers to the Graph

Step 15: Add a marker to the trace for K.

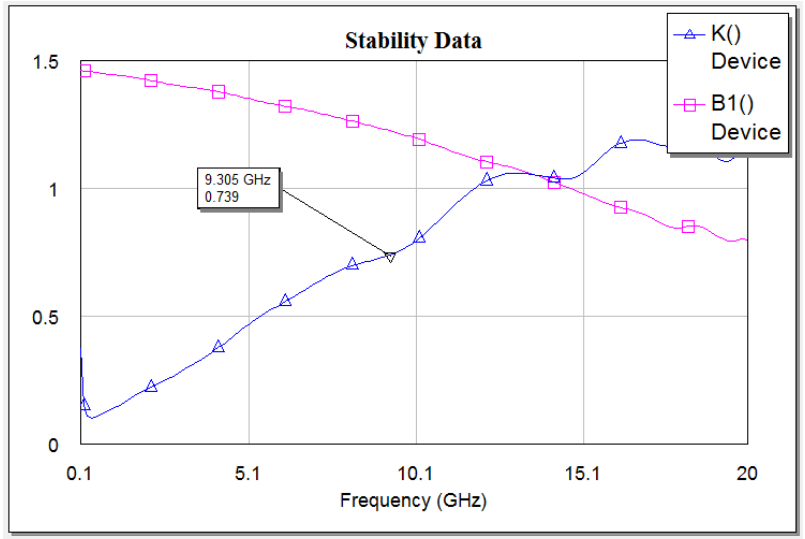
RC on the graph and select
Add Marker (Ctrl M).

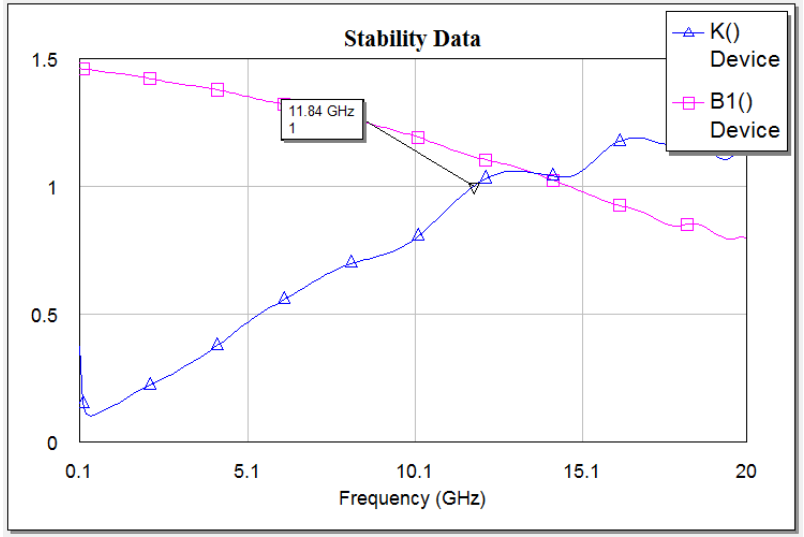
Click anywhere on the K trace to add the marker.

Right click on the marker and select Marker Search - for 1.



Remember K < 1 and/or B1 < 0 is not unconditionally stable.

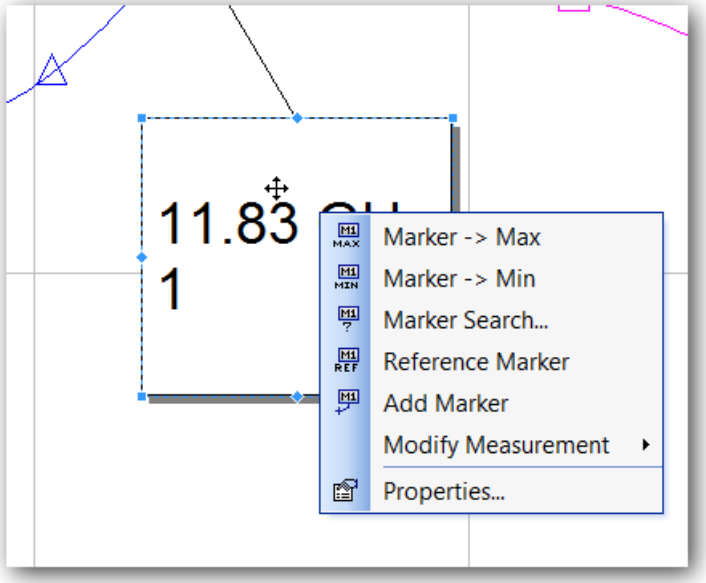


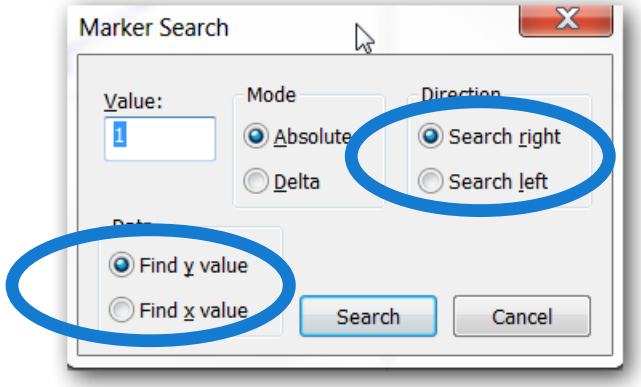


More on Markers

By right clicking on the marker's legend:

- Get the maximum and minimum values of the trace
- Set the marker as a reference.
  - A second marker on the trace is relative to the reference marker.
- Search for a value.
  - Can select X or Y.
  - Need to tell it to look left or right.
  - There could be more than one point with that value – eg. The 3 dB point of a filter.

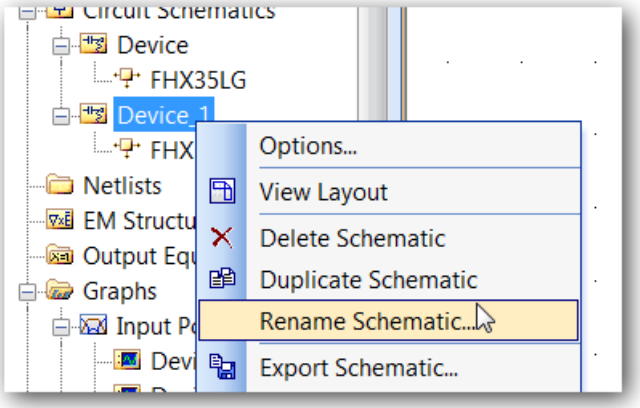




Finish the Schematic

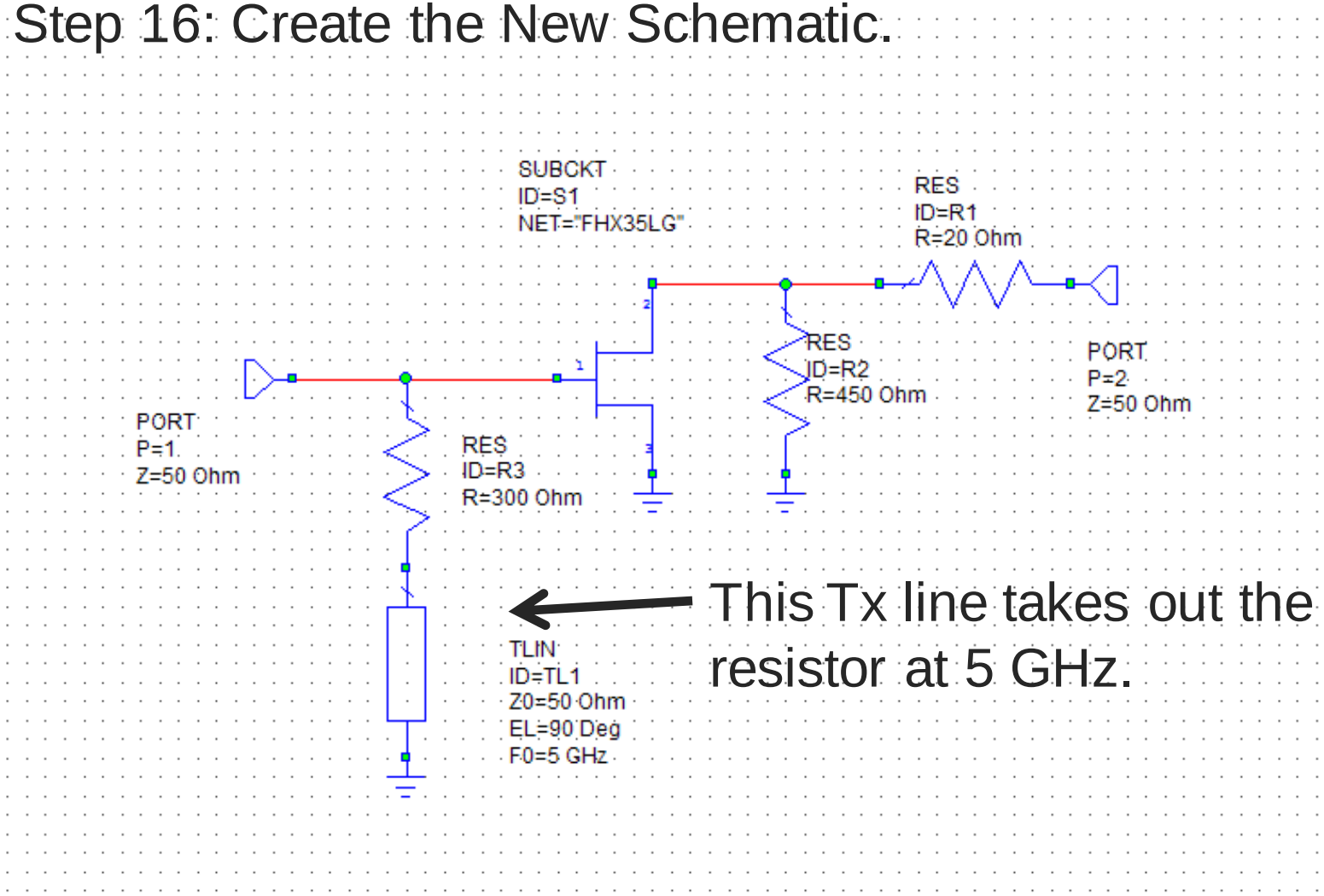
Copy the schematic and rename the copy “Stable Device”.

Tip: The easiest way to do this is drag Device into Circuit Schematics - and Copy of Device will be created. Then right click on the schematic name and rename it.



Stable Device

Step 16: Create the New Schematic.



Update the Graphs with the Stable Device Results

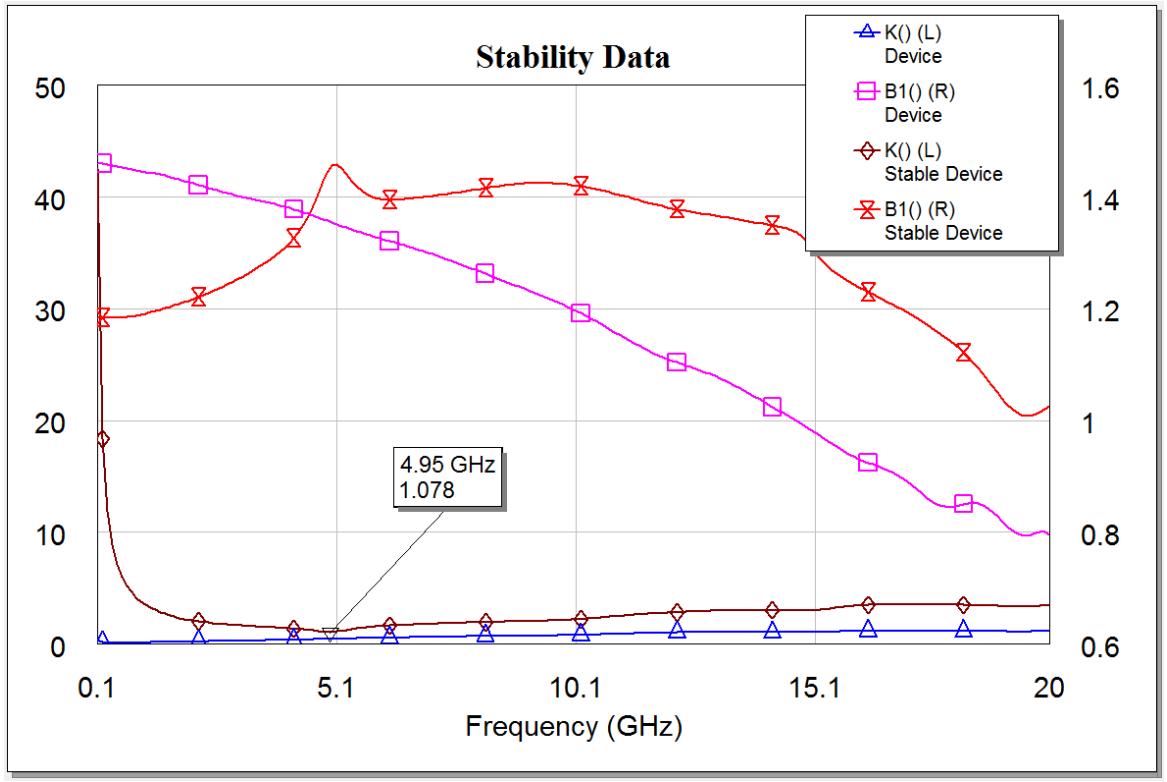
Step 17: Update the graphs with the new Stable Device S-parameters, Gain, Noise, and Stability measurements.

Tip: A quick way to do this - is any measurement can be dragged on top of the graph in the browser - creating a copy. Change the Data Source Name to Stable Device.

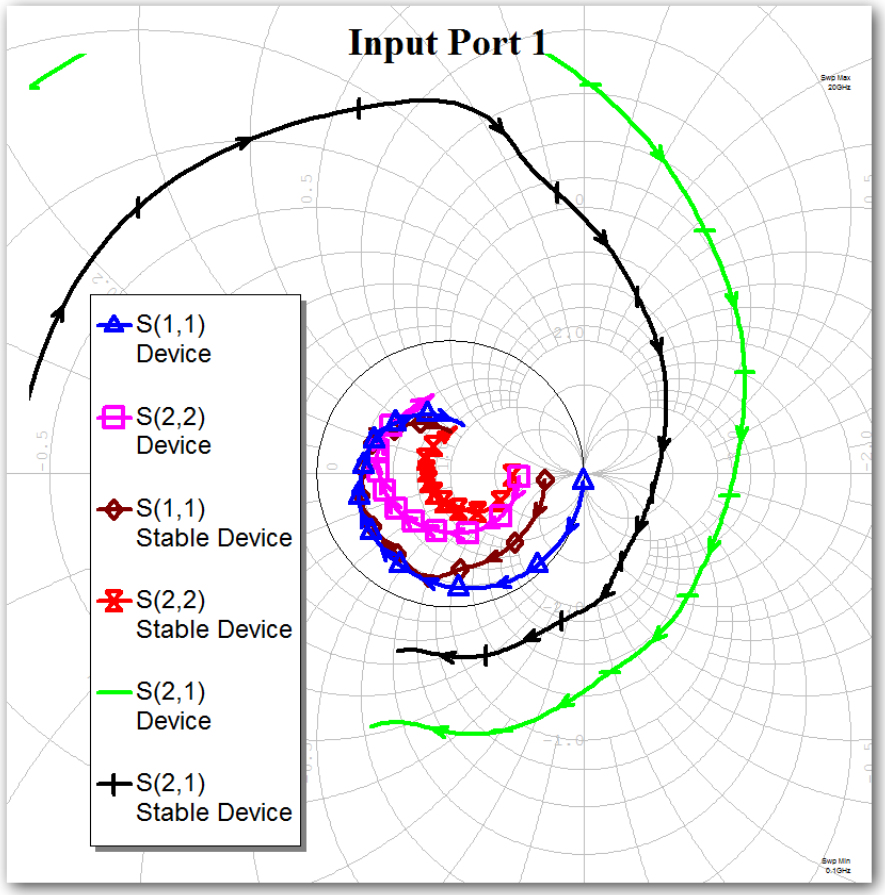
K and B1

K > 1 and B1 > 0

Note: K gets very large near DC. Turn off auto-scaling on the vertical axis. Put B1 on the right axis.

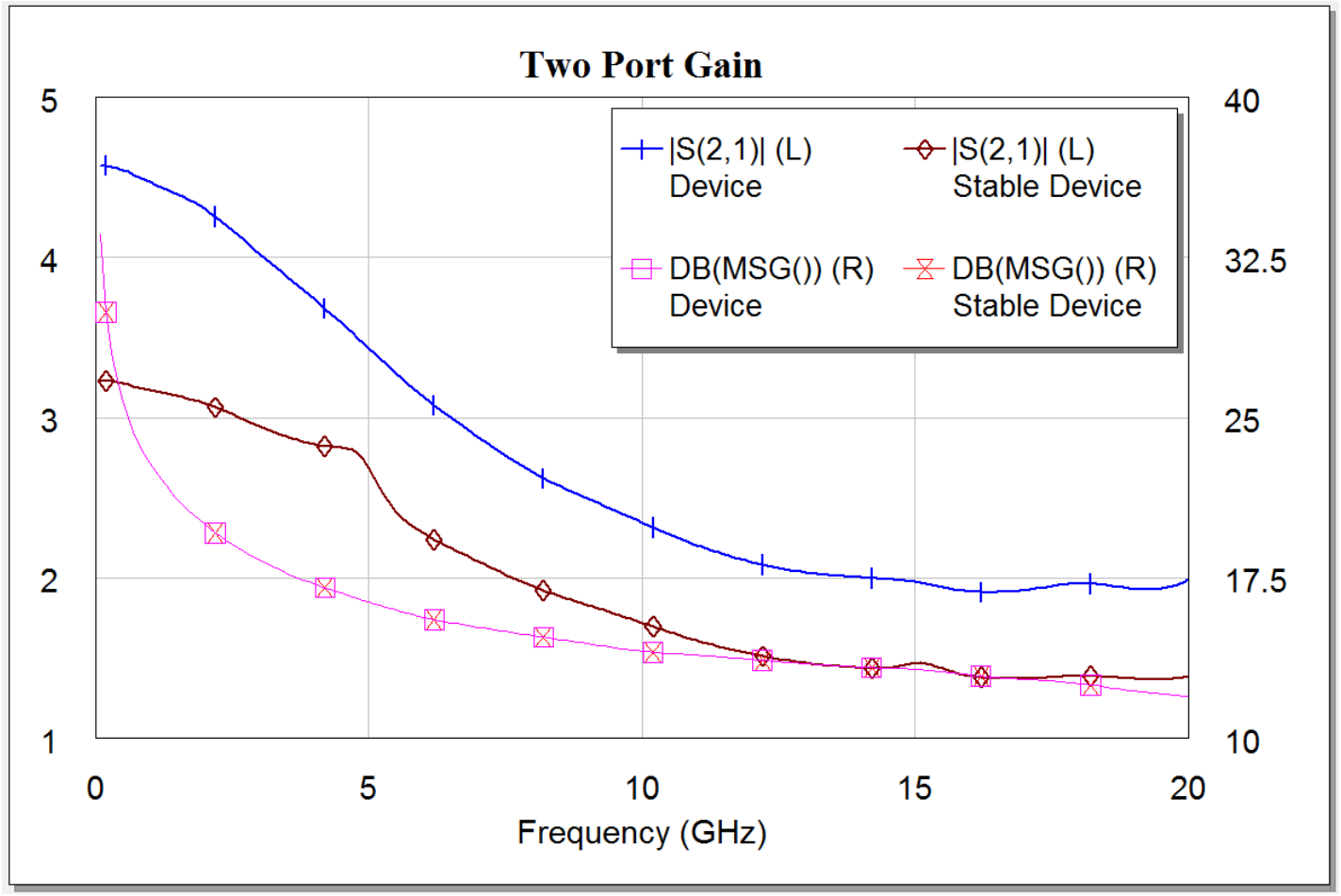


Example - A Low Noise Amplifier - 22



S21 has gotten smaller as expected.

Example - A Low Noise Amplifier - 23



The Gain is lower - as expected.

The Maximum Stable Gain is unchanged – as it should be.

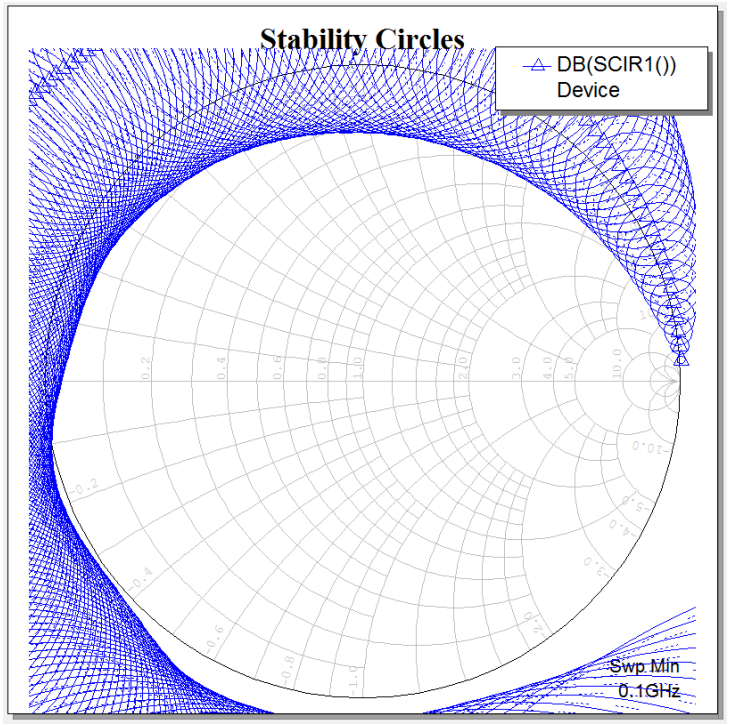
Stability Circles

Step 18: Let's see the stability circles for the input port.

Create a graph - Smith Chart type, named "Stability Circles"

-Add the measurement: SCIR1 (Measurement Type - Circle).

-Use the Source Name " Device". (It's more interesting - not stable.)

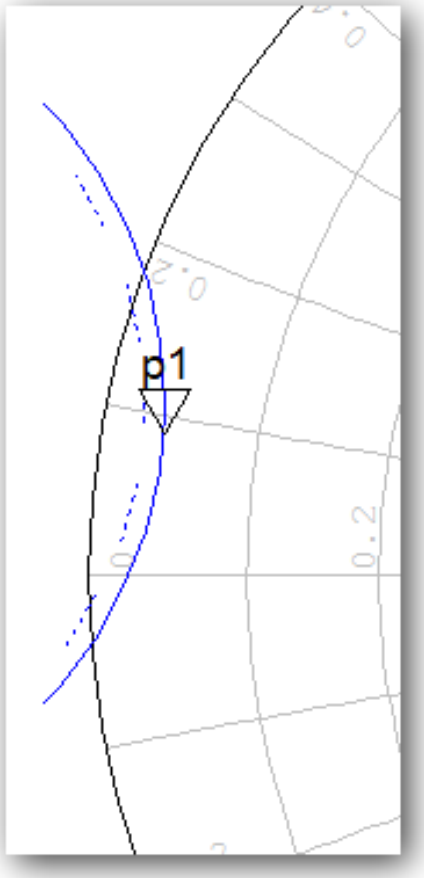


A circle has been added for each frequency.

How to Understand the Circles

There is 1 circle at each frequency.

For each circle -



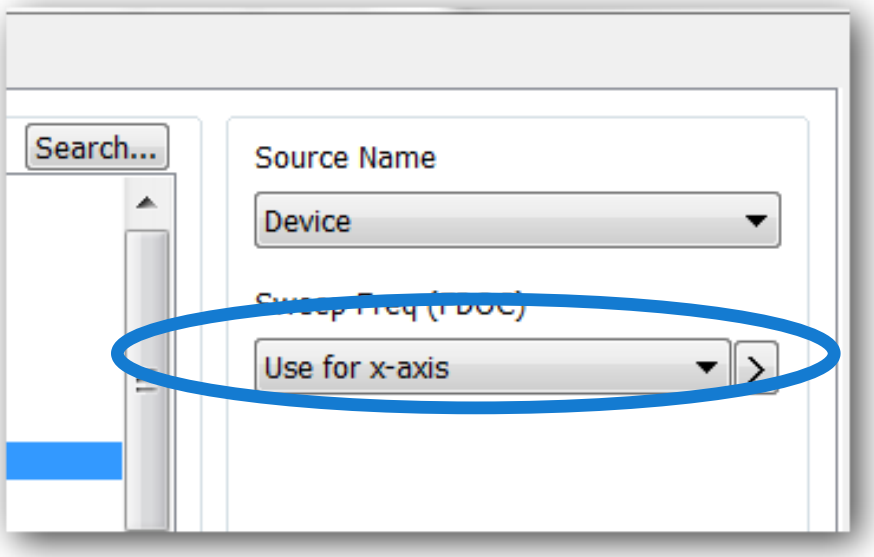
Loads on the dotted side – give an unstable amplifier.

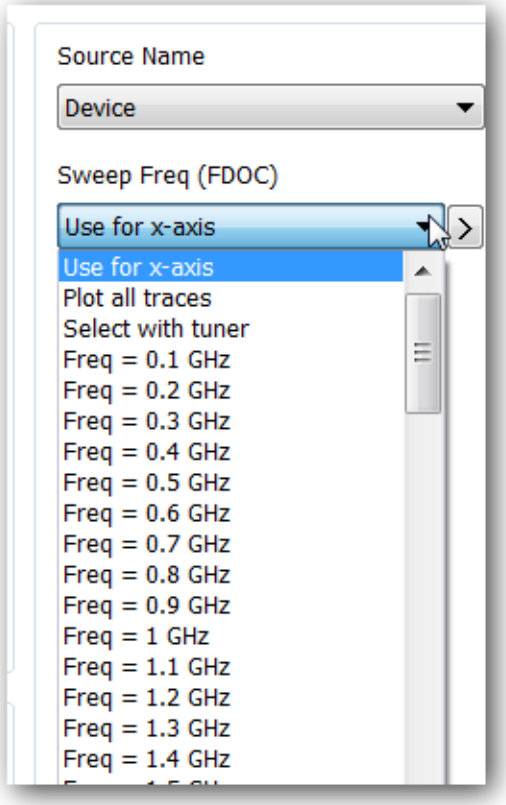
Loads on the solid side give a stable amplifier.

For – SCIR1 – this is the input load.

Fixing the Number of Circles

There is a circle for each frequency. (… more technically – for each value of the “Use for X axis” swept variable).

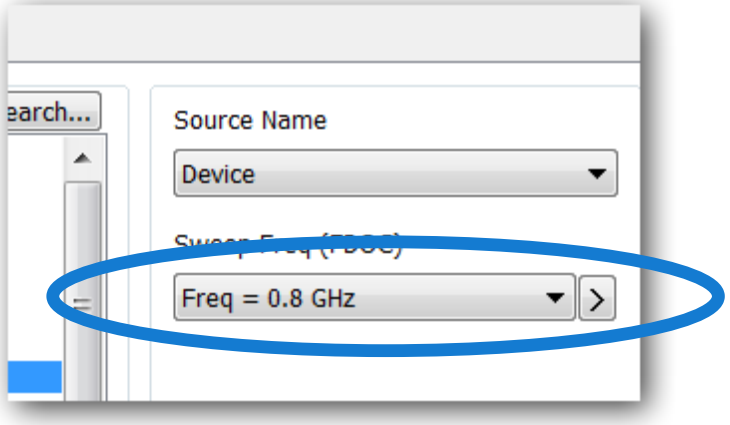




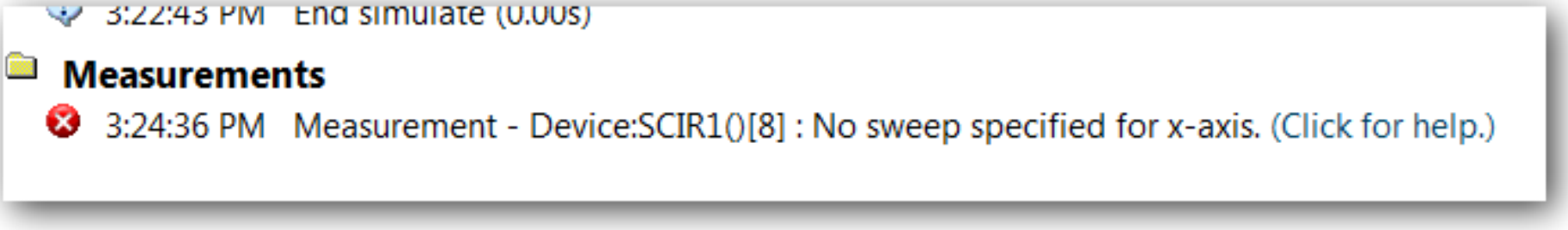
Clicking the down arrow shows them.

What You Can't Do …

Try selecting one frequency …



An error is thrown. You must have something sweeping on the "X axis".



3 Solutions – Method 1 – Fewer Frequencies

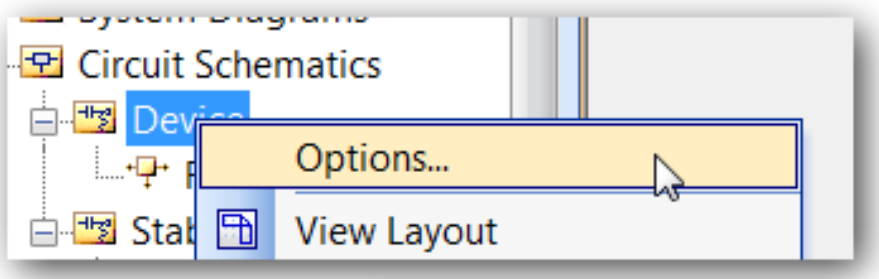
We will look at three solutions.

Method 1: Have fewer frequencies.

- Not very flexible as any other measurement using the schematic is affected.
- Can work if nothing else using that schematic – quick to do.

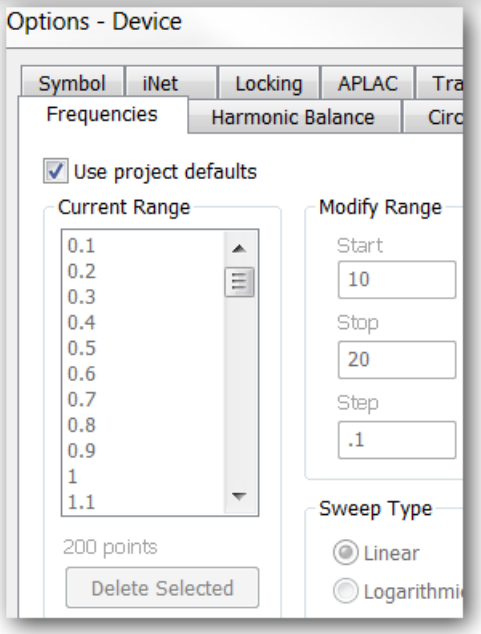
Project and Document Frequencies

On the project browser, open up the Options for schematic – Device.



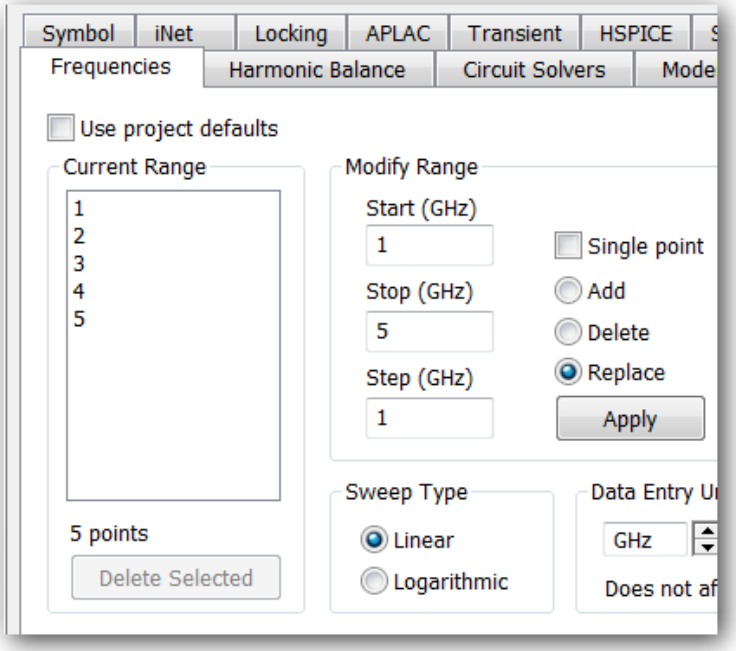
The Frequencies tab shows what frequencies are used by any measurement using this schematic.

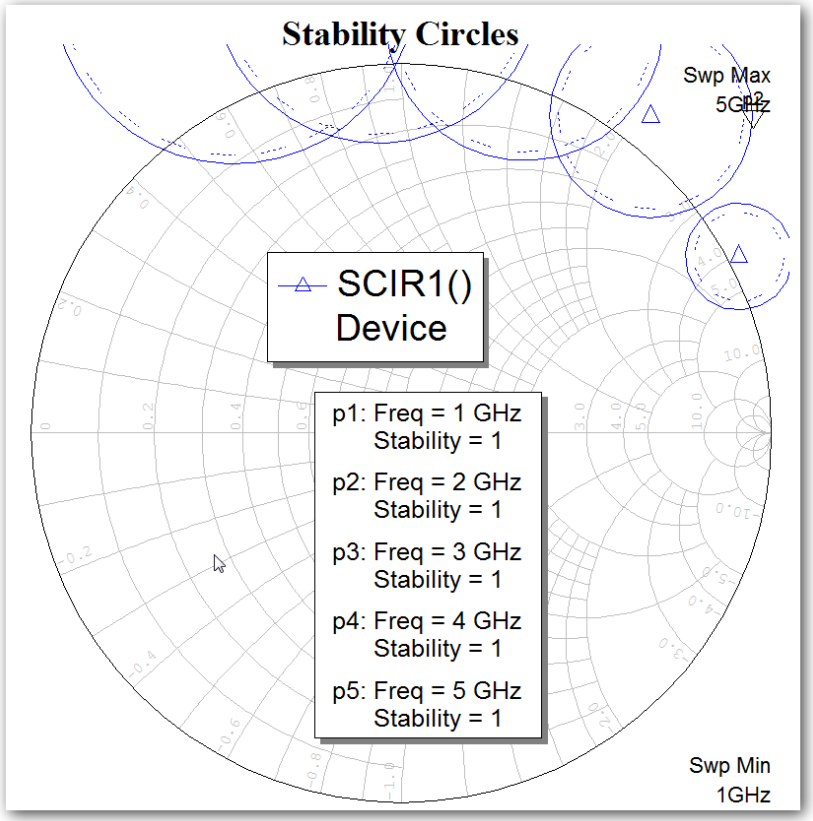
You can uncheck “Use project defaults” and change it.



Project and Document Frequencies - 2

Change it to 1 – 5 GHz, in steps of 1 GHz.

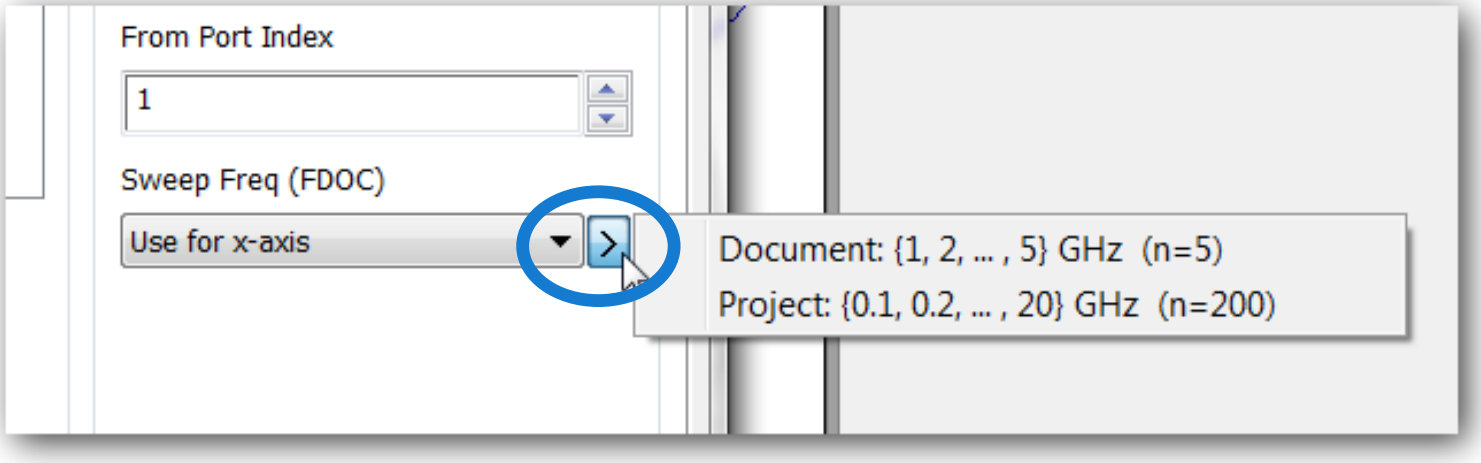




Only 5 circles now – for the 5 simulated frequencies.

Project and Document Frequencies - 3

Look at the measurement dialog box for S11.



If you click the right arrow for the Sweep Freq – there are two choices. By default the local Document frequencies are used. You can go back to the project frequencies if you wish.

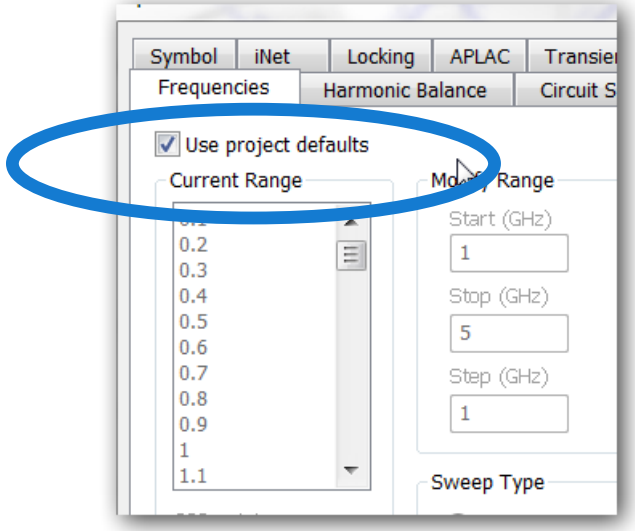
This gives local frequency control at the schematic level.

Fewer Circles – Method 2 – a FREQ Block

The first method has the problem that any measurement using the schematic – Device – is affected.

Method 2: We add a swept frequency block to the schematic. We then can point to this block when we use the circle measurements.

Go back to the schematic – Device – and reset the Document frequencies to the defaults.

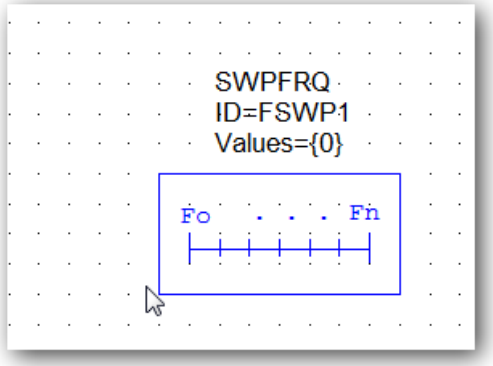


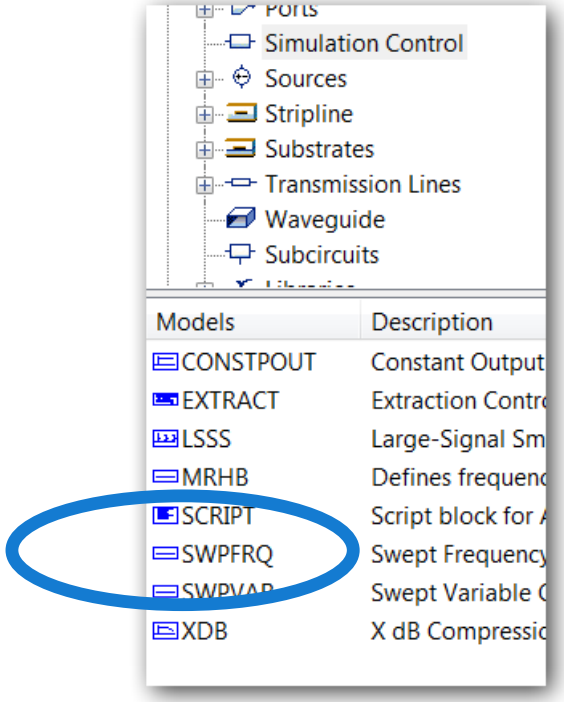
FREQ Block

On the schematic – Device – add a SWPFRQ block.

There are two ways to get it.

1. In the Elements Browser – it's under Simulation Control – SWPFRQ.

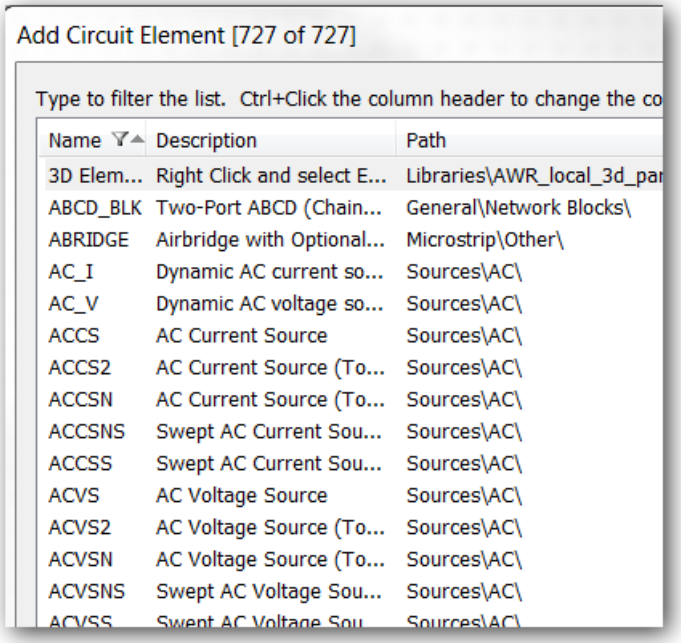




FREQ Block - 2

2. Get it from the element browser menu.

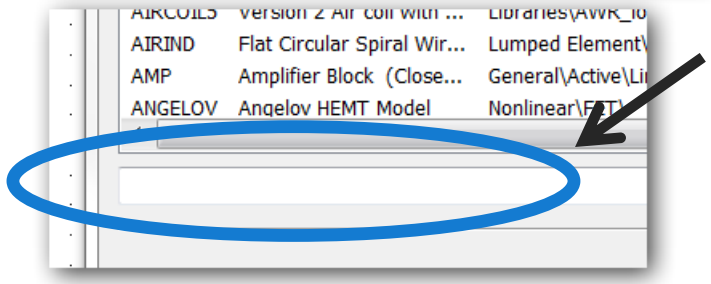
In the schematic – type – Ctrl + L.



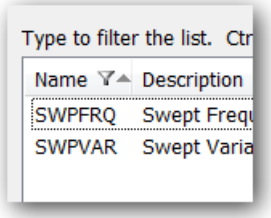
All the elements in the software.

You can sort by Name or by Keywords.

Ctrl + click at a top of a column gets to ready to search on that column.



Type in SWP here to sort.



Filling in SWPFRQ

We tell it what frequencies we want.

Note: We must enter in Hertz – not GHz. This is because if you changed project units to MHz for example – you would change the frequencies.

You can enter values in an array:

```
SWPFRQ
ID=FSWP1
Values={1e9,3e9}
```

E.G. – 1 and 3 GHz. Curly brackets are used for arrays.

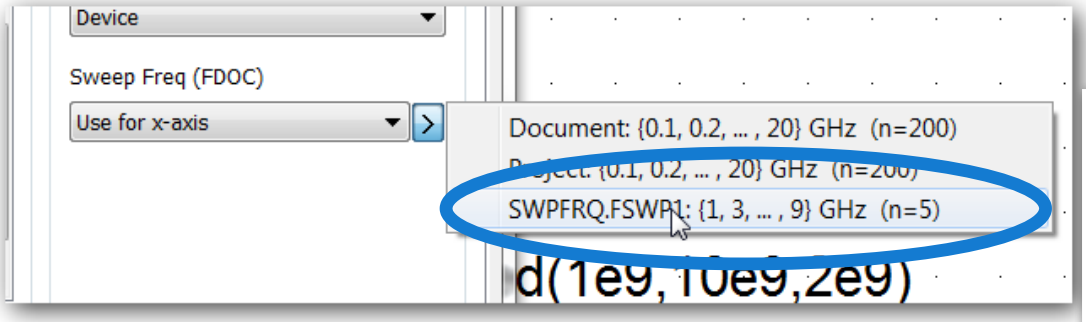
```
SWPFRQ
ID=FSWP1
Values=stepped(1e9,10e9,2e9)
```

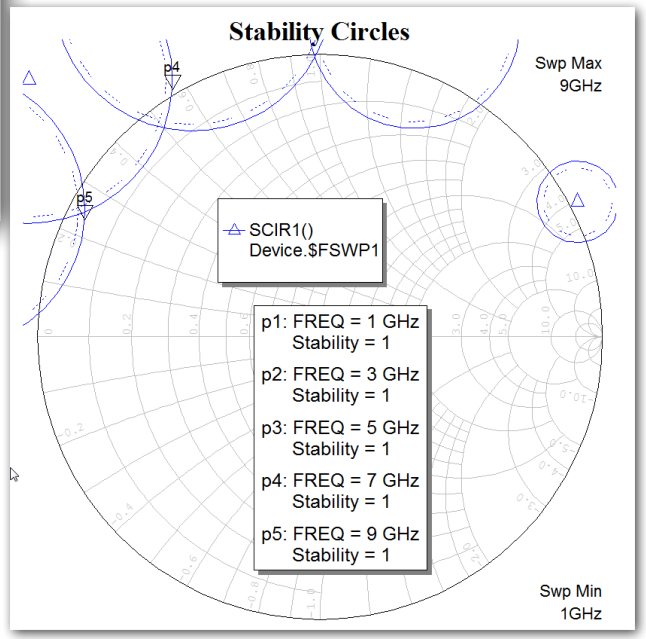
A function – parentheses are used. This is 1 to 10 GHz in steps of 2 GHz.

Use this one.

Using the SWPFRQ Block

In the measurement – SCIR1 – we now can pick the SWPFRQ block with the right arrow of the swept frequency measurement.





Uses only 1, 3, 5, 7, and 9 GHz circles.

Fewer Circles – Method 3 – Another Swept Variable

Change the measurement back to using the default frequencies.

The trouble is the measurement wants a swept variable for the “X axis” to sweep.

We will create one on the schematic, and have the measurement use it.

Then, the frequencies can be picked as we wish.

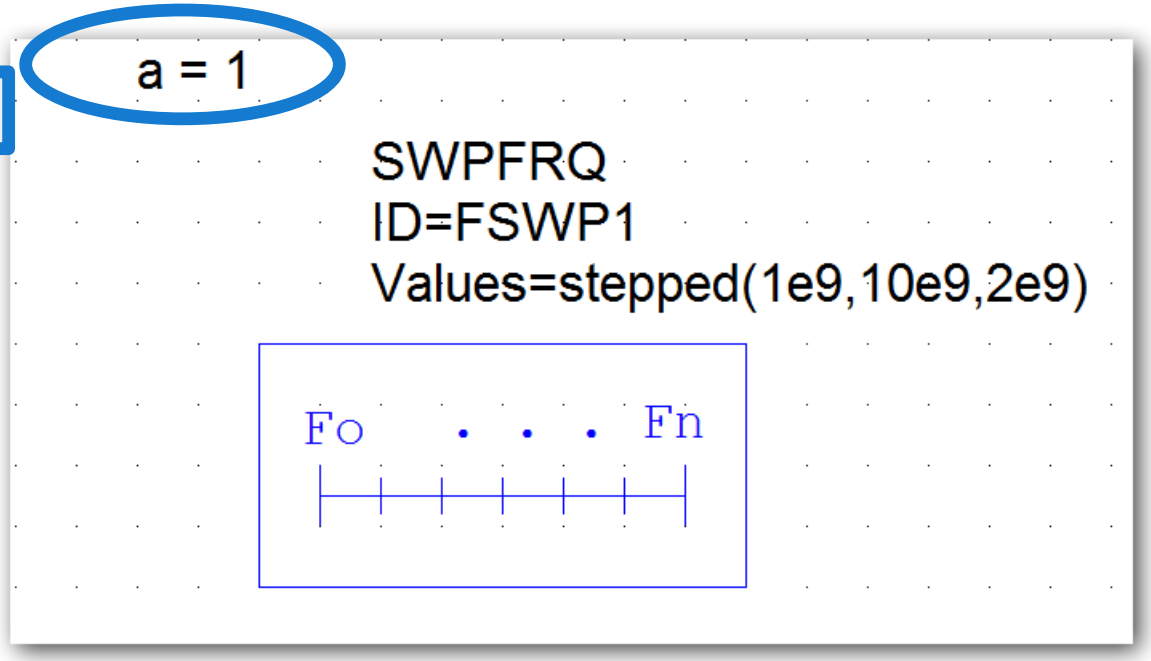
Create a Dummy Swept Variable

In the schematic – Device – put in a variable.

Type Ctrl +E – for add an equation.

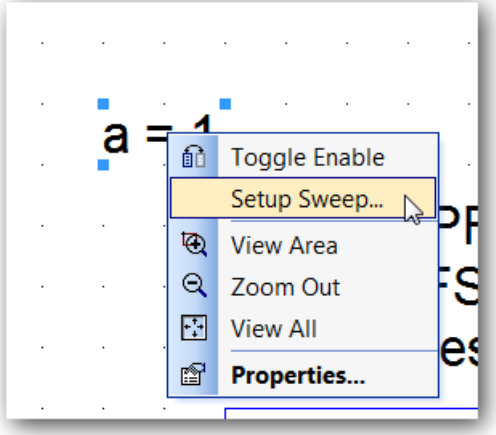
Create an equation – a = 1

Tip: It can go anywhere on the schematic.

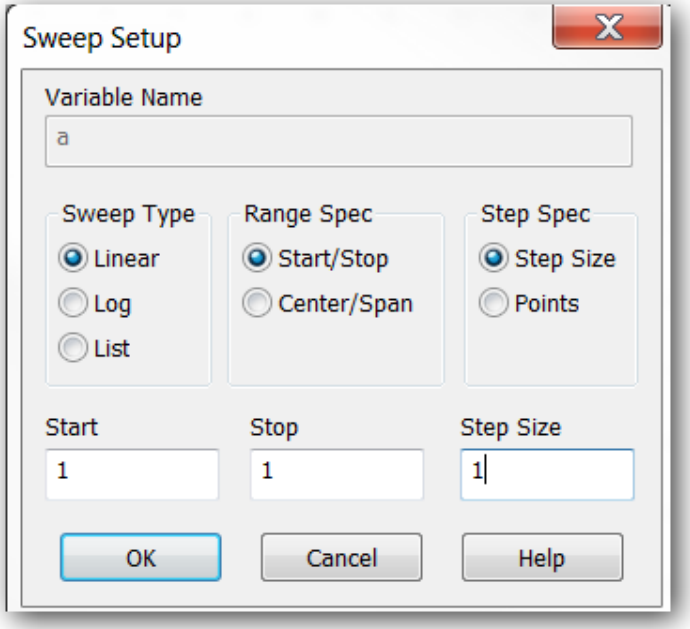


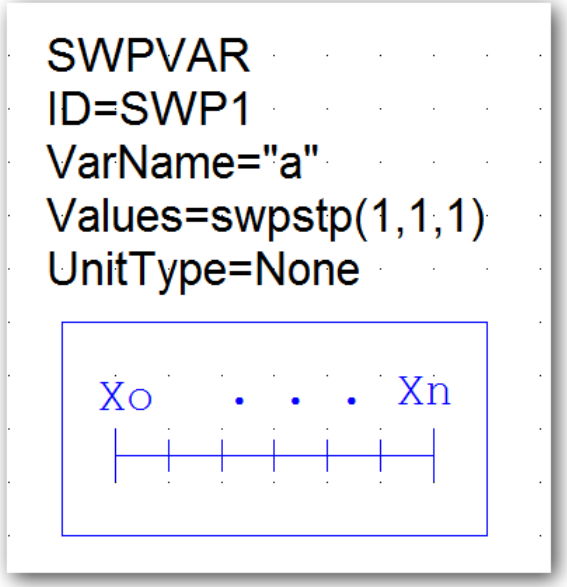
Sweep the Variable

Right click on a = 1 > Setup Sweep.



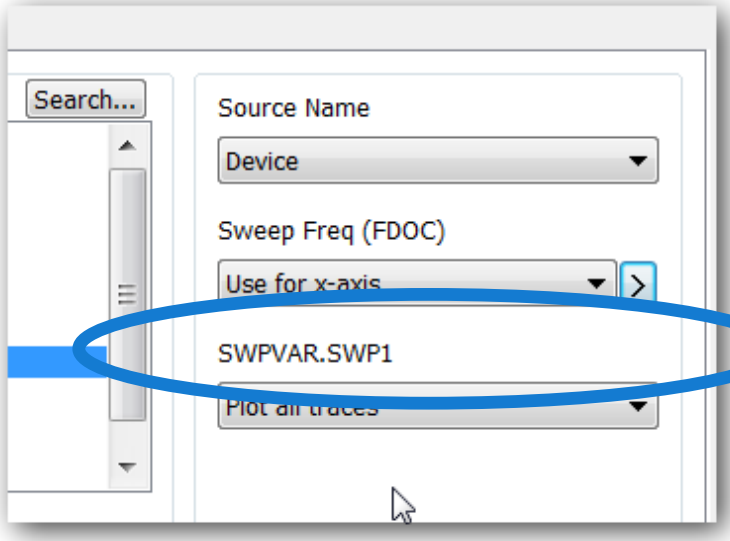
Fill in the sweep values – it doesn't matter too much what you pick. We want just one value.



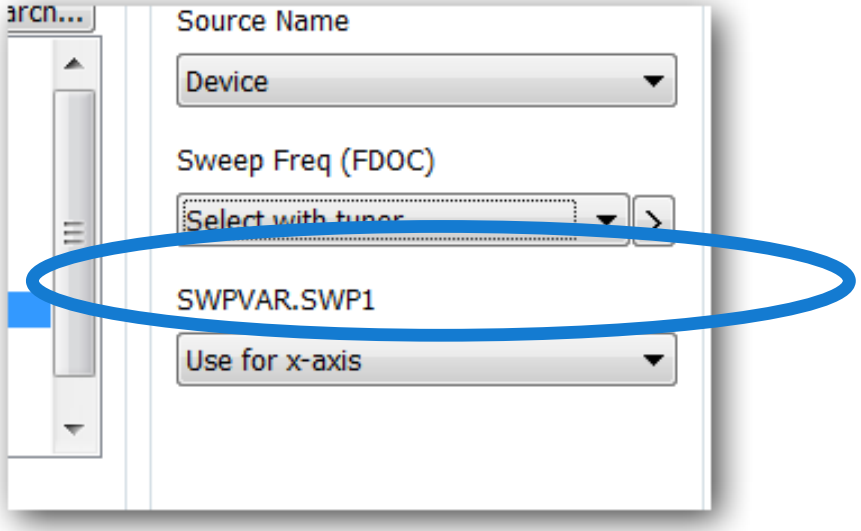


The SWPVAR block is created.

Modify the Measurement



The SCIR1 measurement now has two boxes – as two things are sweeping – the frequency and “a”.



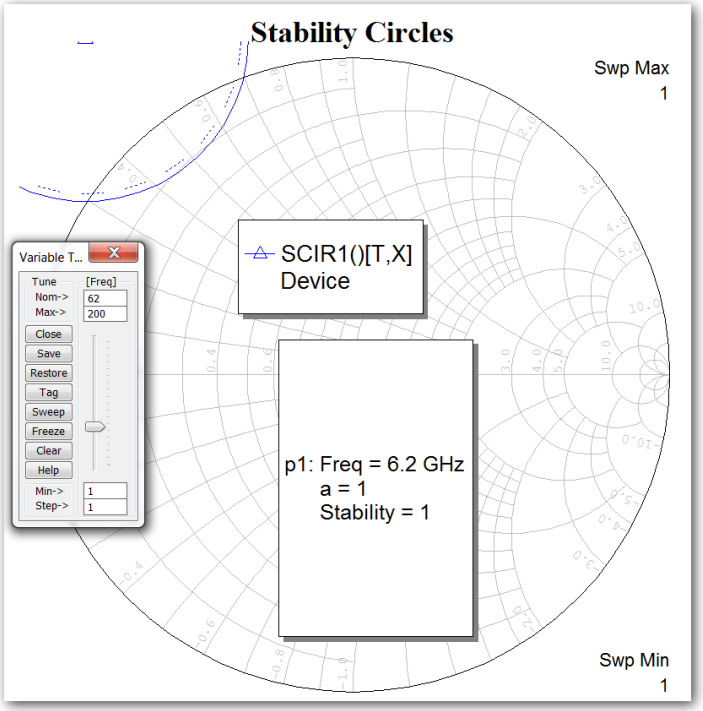
Change “a” to use the “X axis”. Then – the freq – we can use Select with Tuner.

Use the Tuner to Change the Frequency

Open up the Smith Chart – Stability Circles.

Bring up the Tuner – It is the slider icon.

Or – Simulate > Tune.

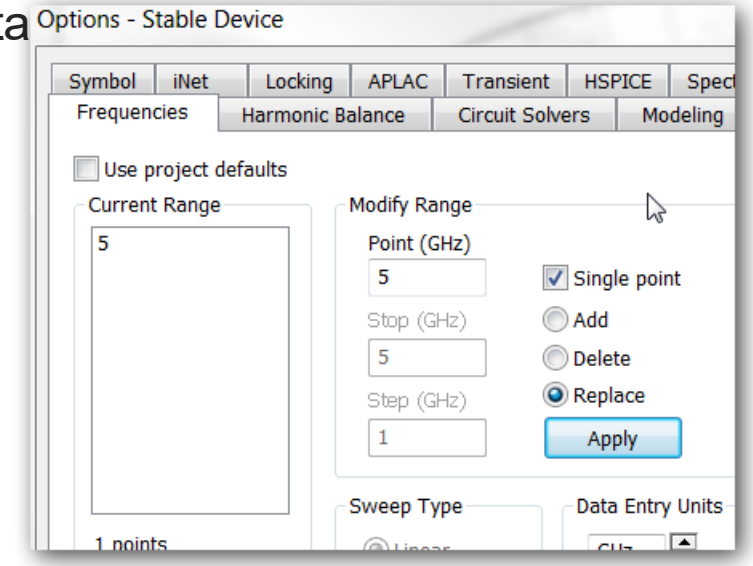


As you tune through the 200 frequencies – one stability circle shows for each frequency. The trick is the variable “a” is being used for the master swept variable.

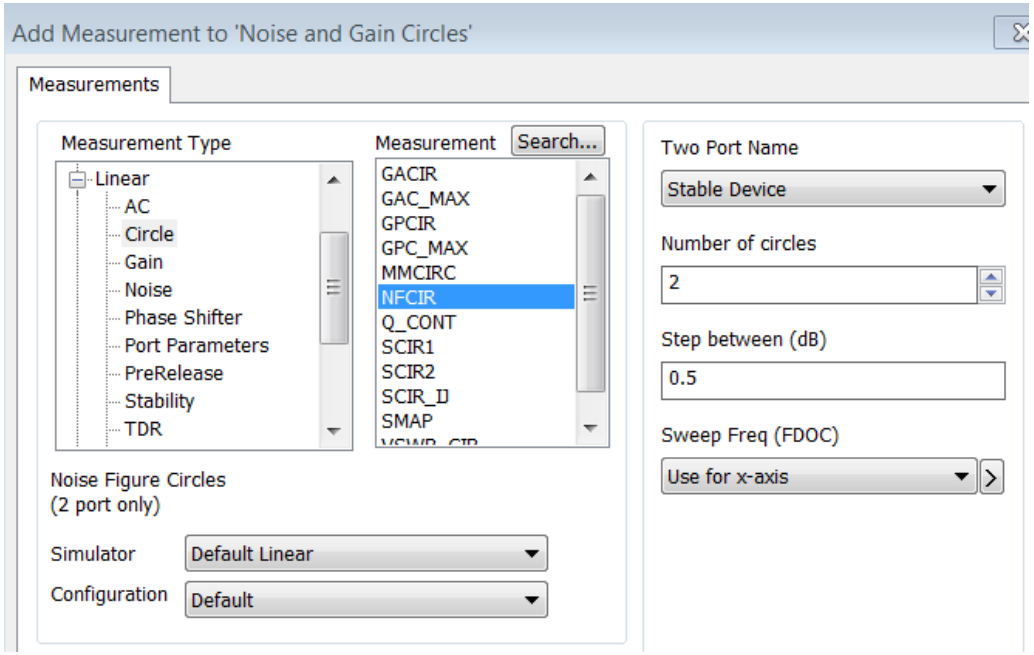
Noise and Gain Circles

Step 19: Add a Smith Chart called “Noise and Gain Circles”. We will work with the “Stable Device” data

Set the local document frequencies to only 1 point - 5 GHz. Right click on Stable Device > Options > Frequencies Tab.



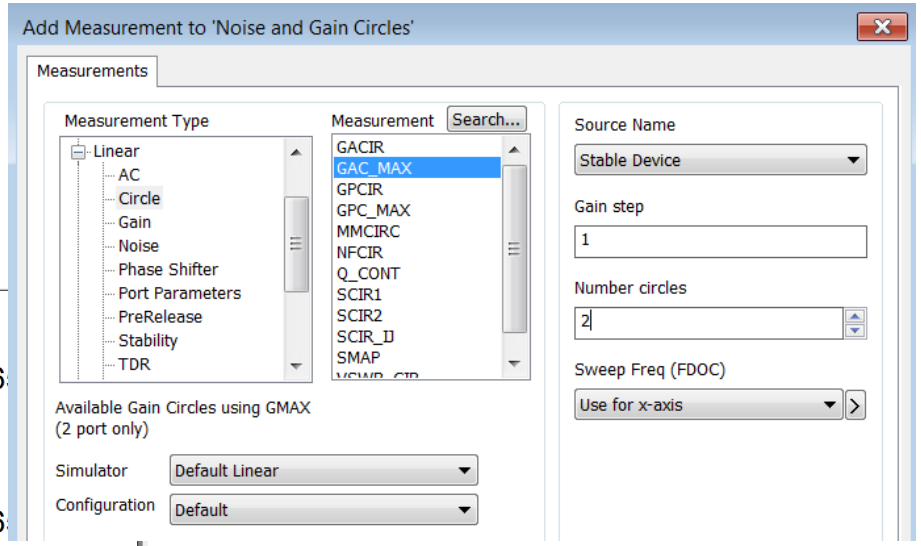
Add the measurement NFCIR (Linear > Circle) with 2 circles and 0.5 dB steps.

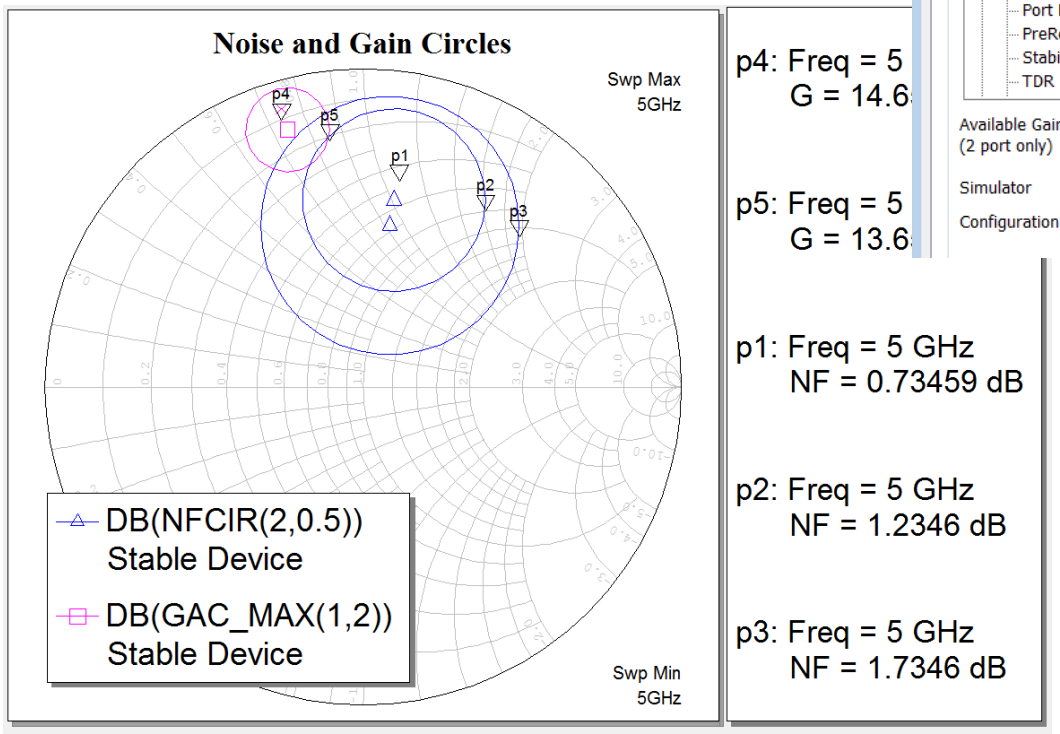


Example - A Low Noise Amplifier - 31

Add GAC_MAX - Available Gain (Linear > Circle)

with a Gain step 1 and 2 circles.





p4: Freq = 5
G = 14.6

p5: Freq = 5
G = 13.6

p1: Freq = 5 GHz
NF = 0.73459 dB

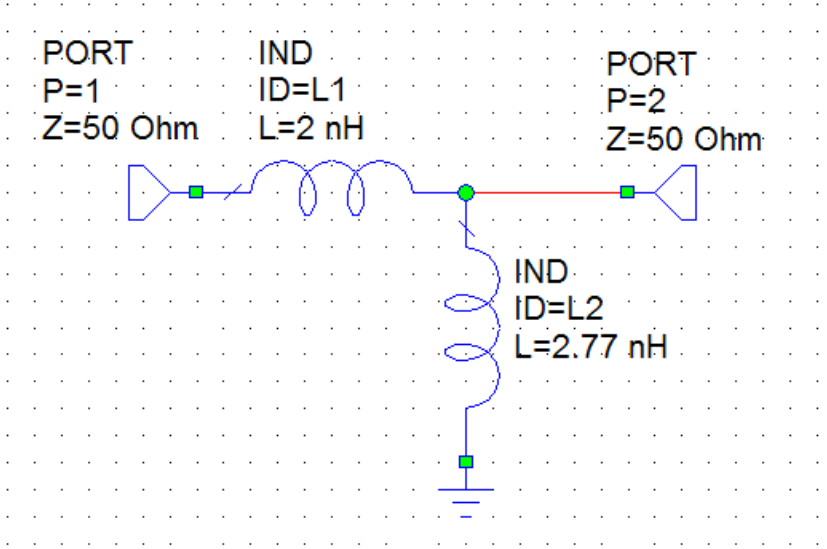
p2: Freq = 5 GHz
NF = 1.2346 dB

p3: Freq = 5 GHz
NF = 1.7346 dB

A Matching Circuit

Let's make a matching input circuit.

Step 20: Create a schematic "Input Matching Circuit"



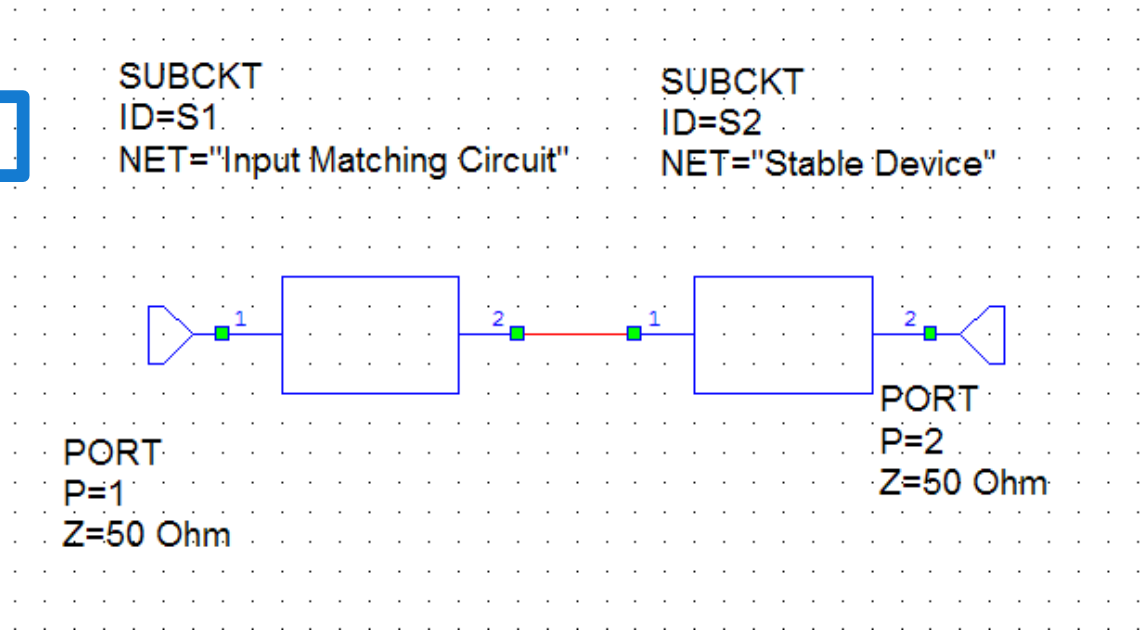
Create the Final Amplifier

Step 21: Create a schematic - “Amp”

- Include “Stable Device” and “Input Matching Circuit” as subcircuits.

Tip: Ctrl + K for adding subcircuits.

Use normal grounding.



Amp Schematic

Window in Window Technology

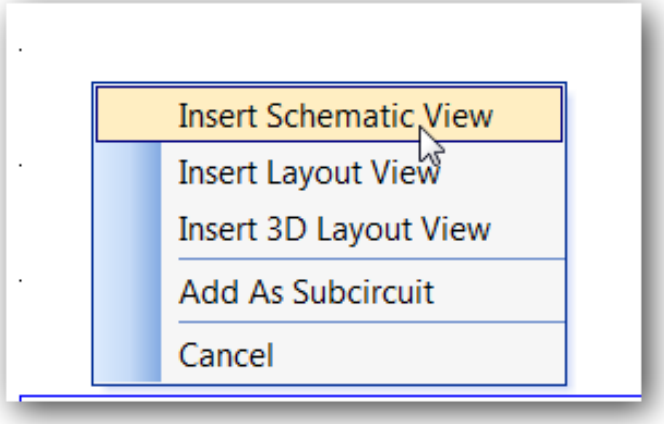
To make the schematic look nicer –

We can add a picture of the subcircuit schematics.

Right click and hold down the mouse on the Input Matching Circuit icon.

Release it.

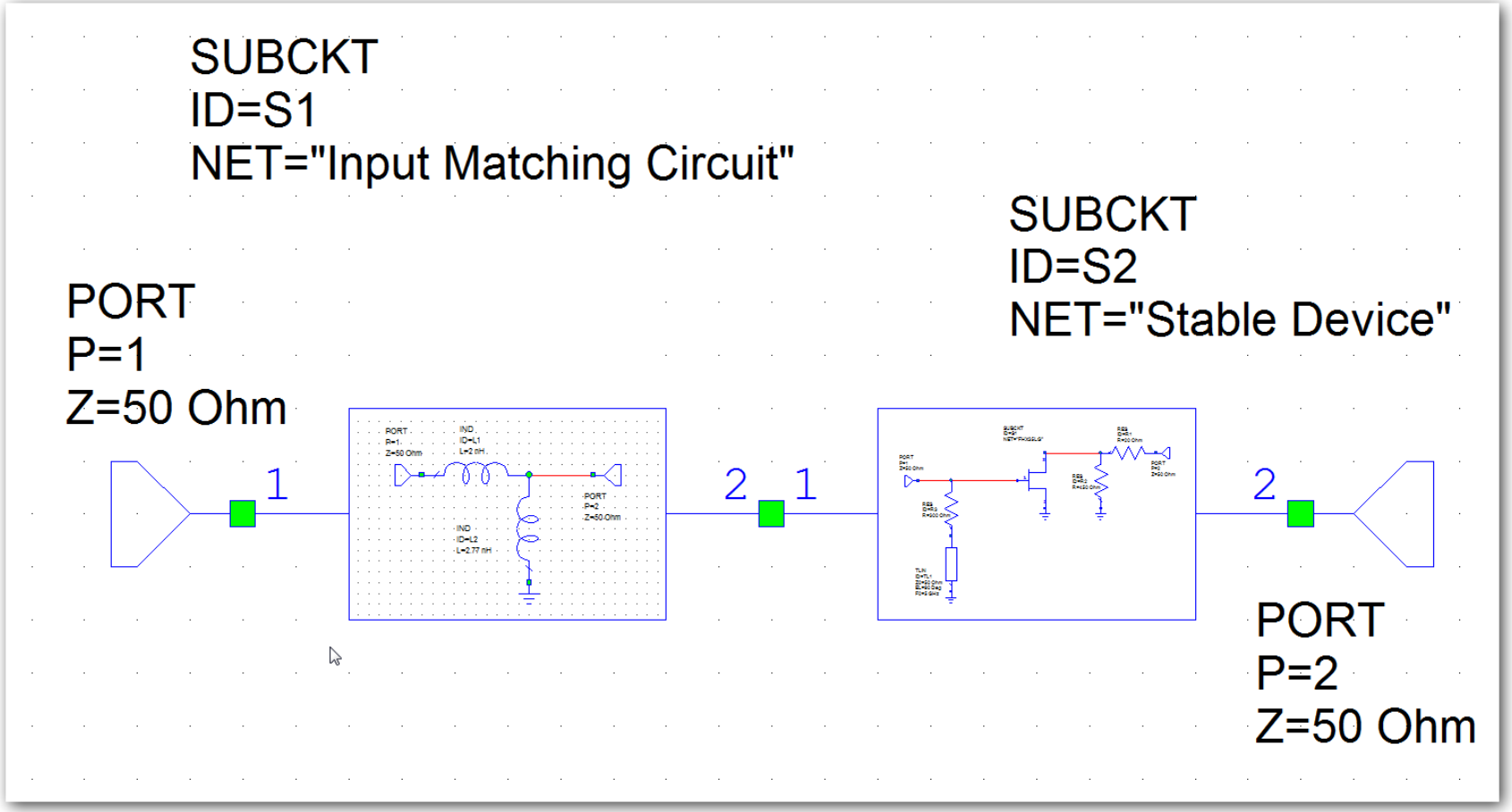
Draw where you want the picture.



You can do the same for

- Layout
- Graphs

Using Window in Window



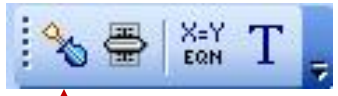
Tune the Matching Inductances

Step 22: Tune the L's to get a good compromise between Gain and NF.

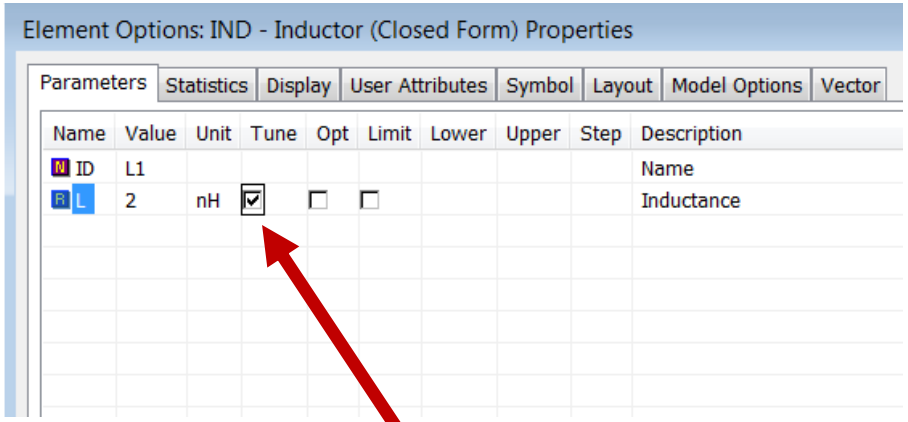
In "Input Matching" select L1 and L2 for tuning.

-Method 1: Use the tuning tool. Select each of them.

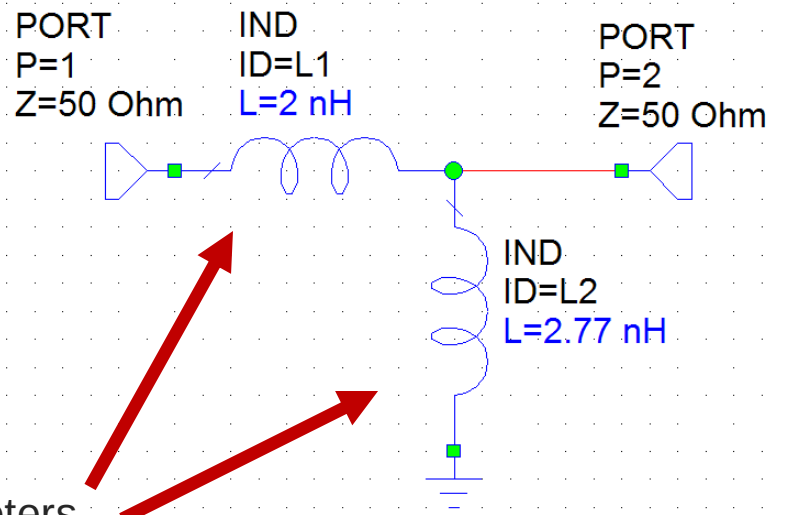
-Method 2: Select Properties for each of them.



Equations Toolbar



Set to tune 0 to 10 nH.



When selected for tuning - the parameters turn blue.

Example - A Low Noise Amplifier - 36

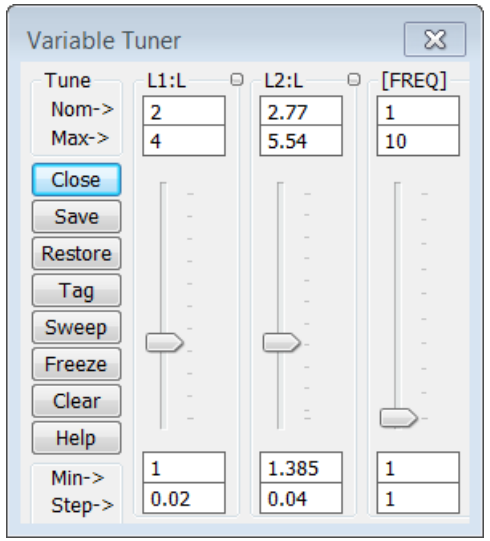
Step 23: Tune the L's to get a reasonable compromise between NF and Gain.

- Set the Document frequencies of Input Matching Circuit to be 5 GHz.
- Add S22 of "Input Match" to the graph Noise and gain Circles.

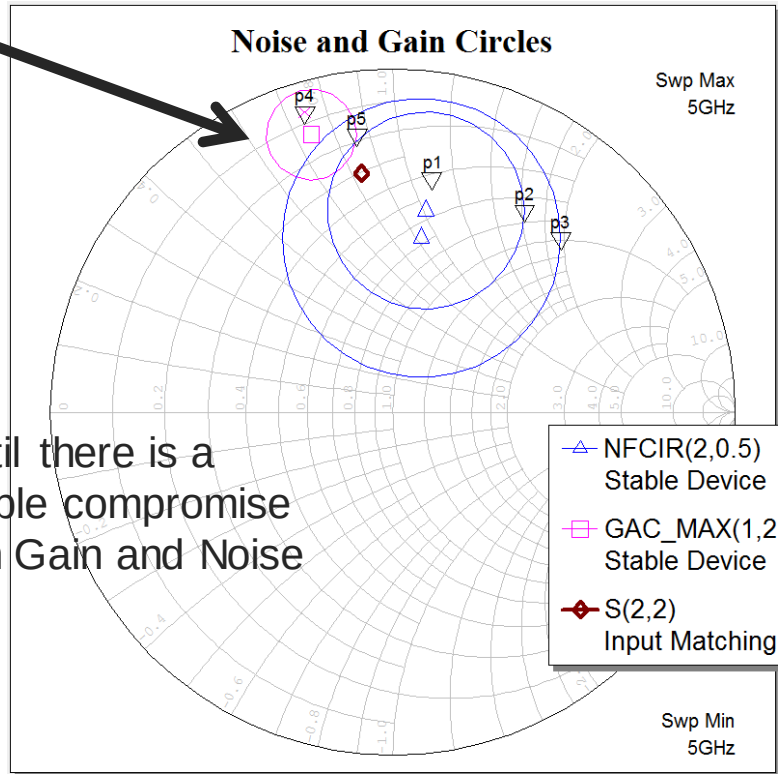
Equations Toolbar

S22 of your input matching will equal S11 of your stable device.

Tuner

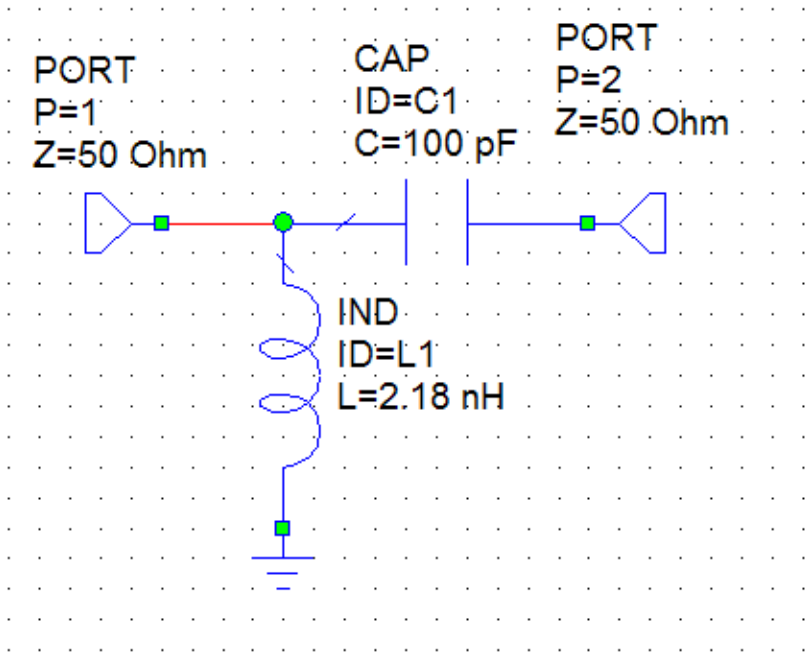


Tune until there is a reasonable compromise between Gain and Noise Figure.



Output Matching Circuit

Add an “Output Matching Circuit”.



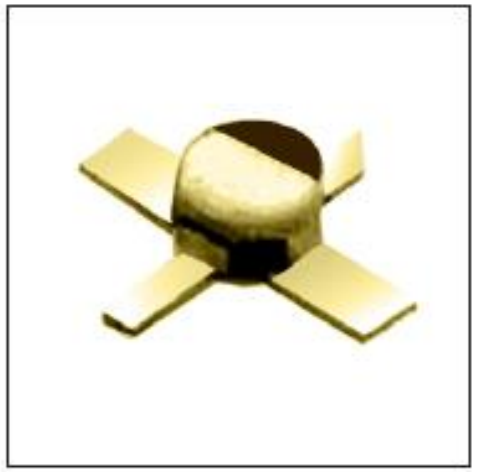
Tune the values to get maximum gain.

You can add - S21 of the “Amp” to the Two Port Gain for example, and tune over the C and L’s.

Note: We have not used simultaneous, conjugate match designs - so the output circuit will influence the design of the input circuit.

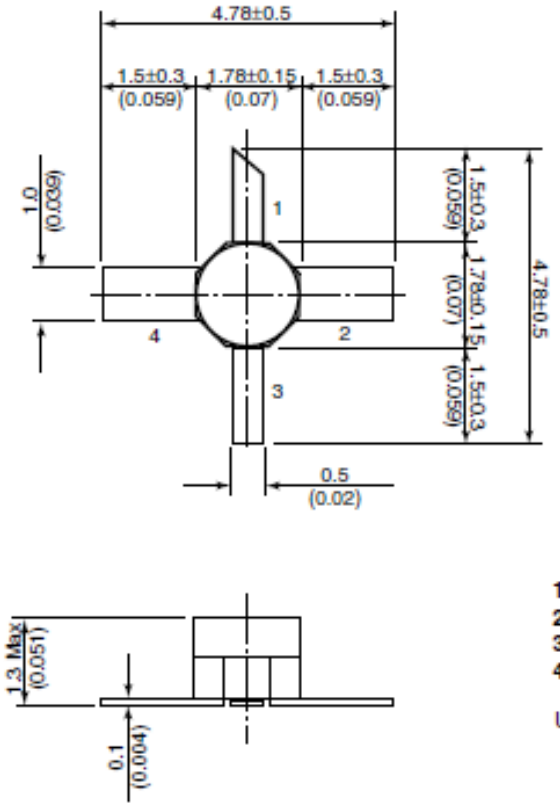
Package / Footprint – Layout for Discrete Components

Package Outline Drawings



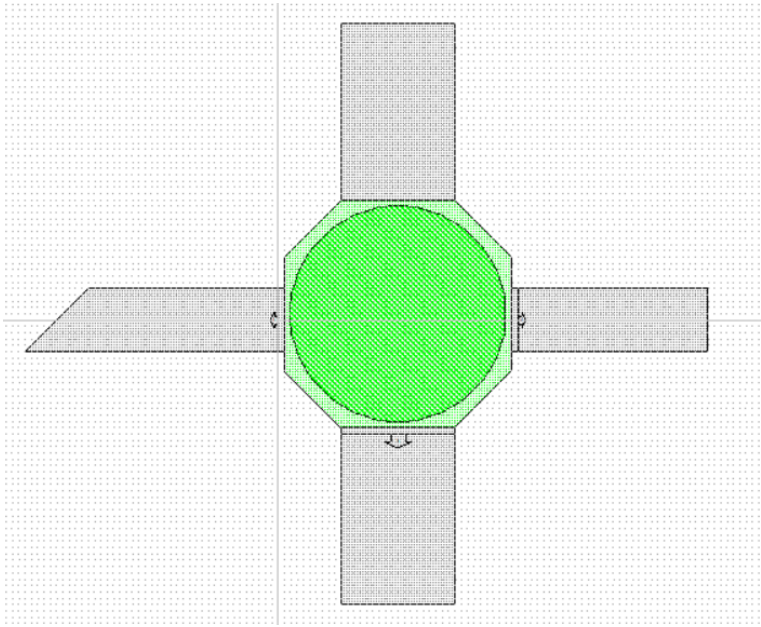
Case Style "LG"

Metal-Ceramic Hermetic Package



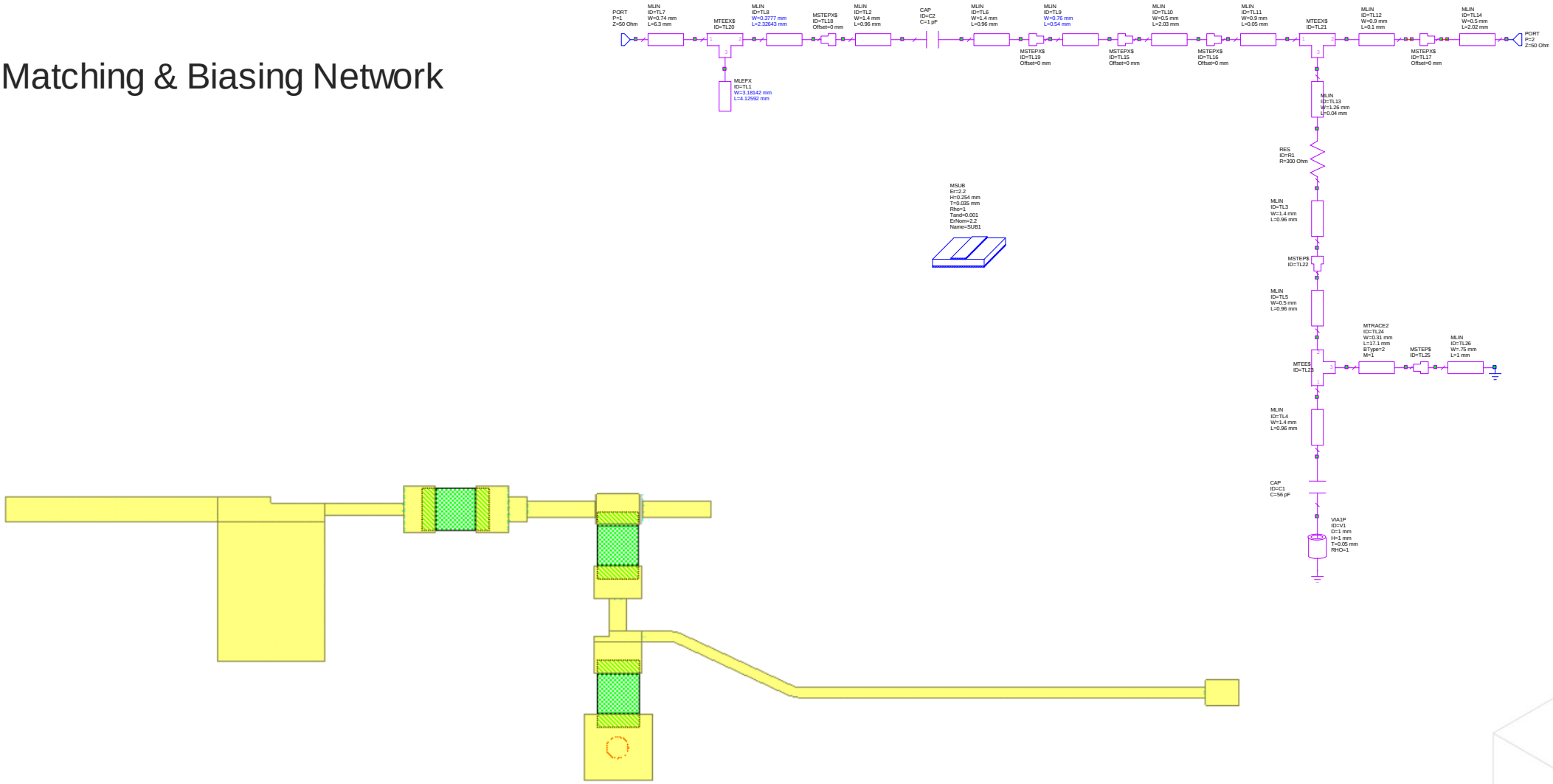
1. Gate
2. Source
3. Drain
4. Source

Unit: mm(inches)



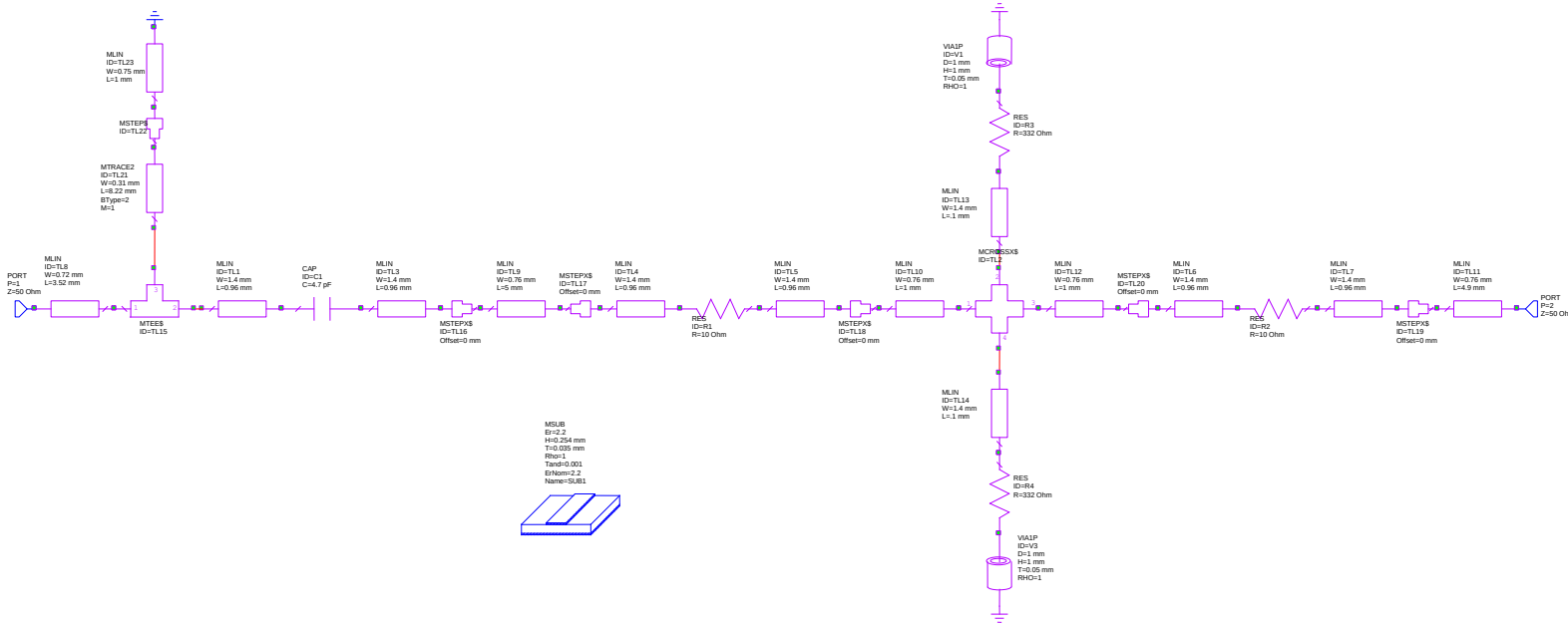
Input Matching Circuit

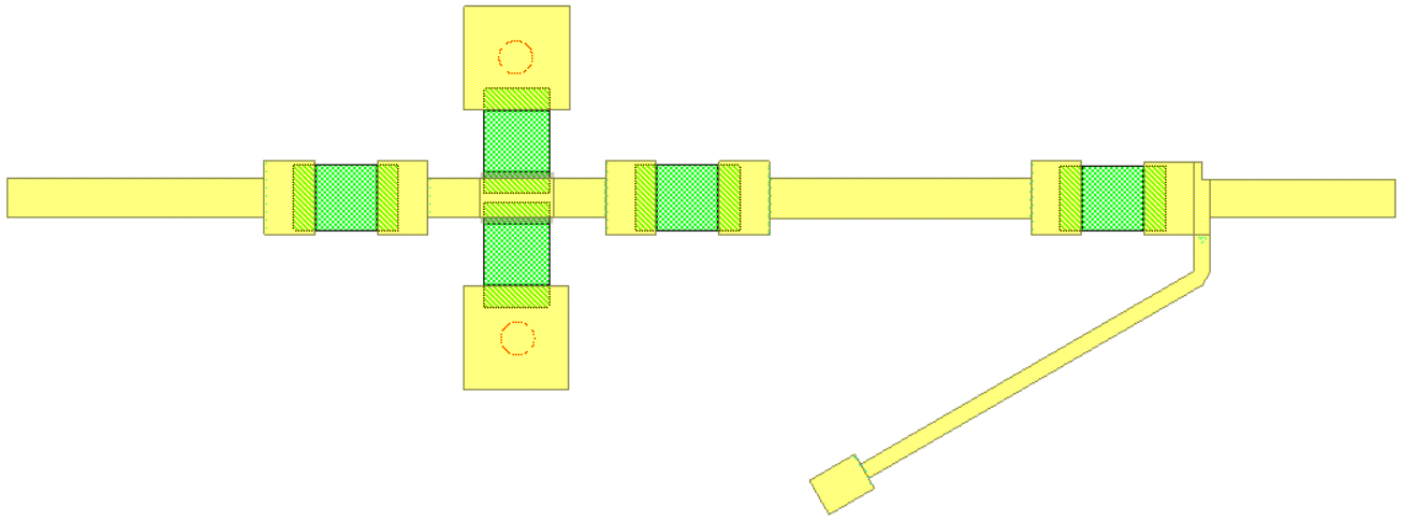
Complete Input Matching & Biasing Network



Output Matching Circuit

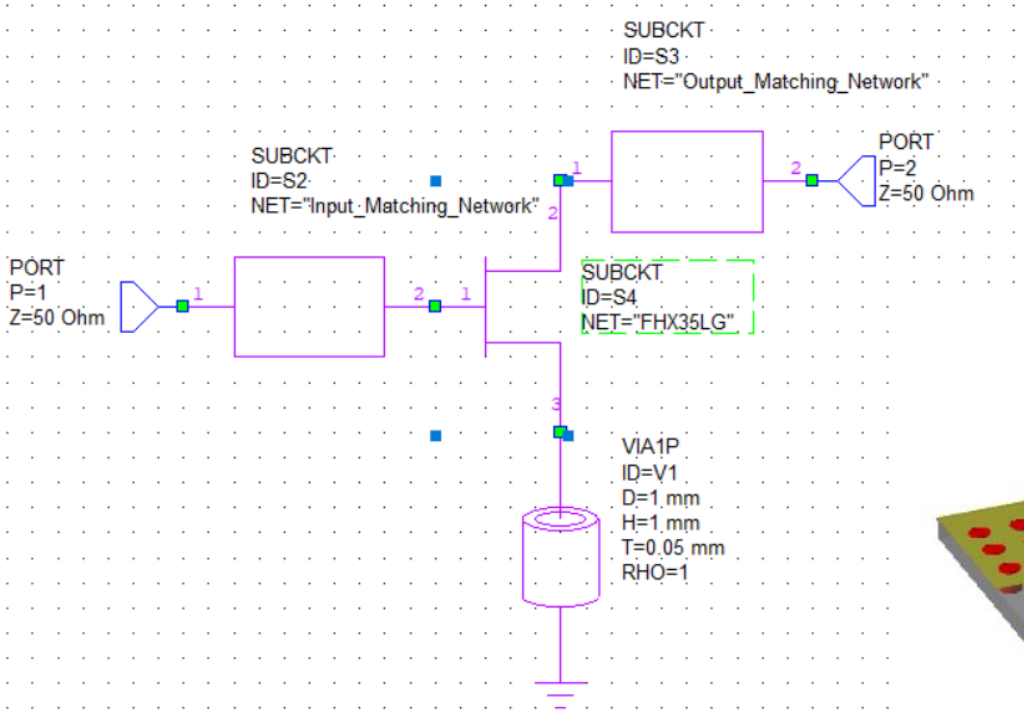
Complete Output Matching and Biasing Network

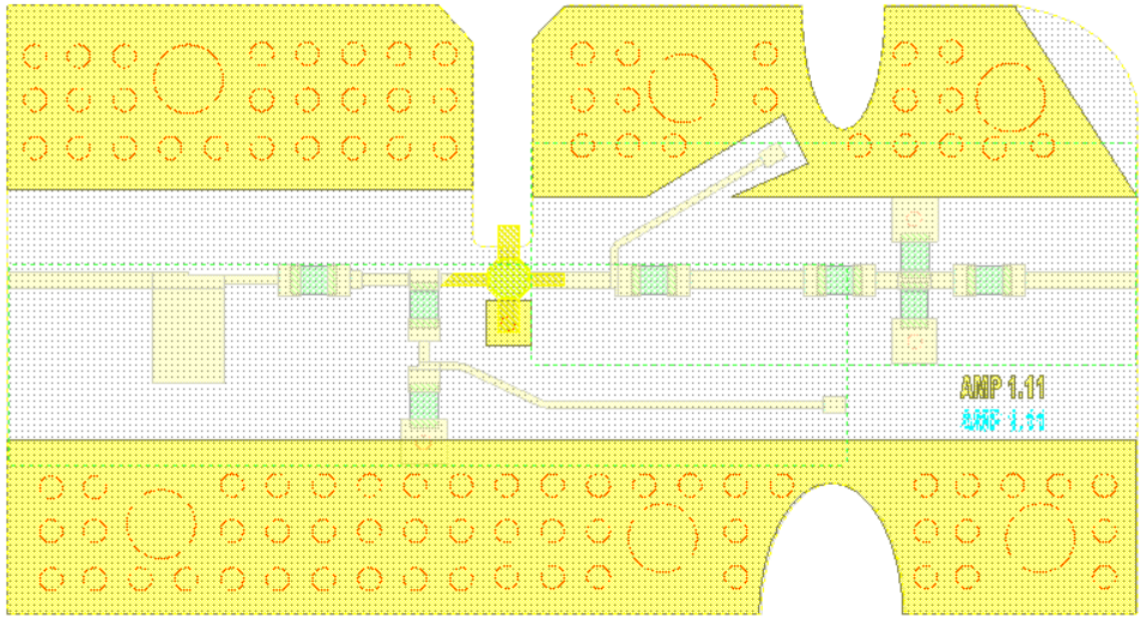


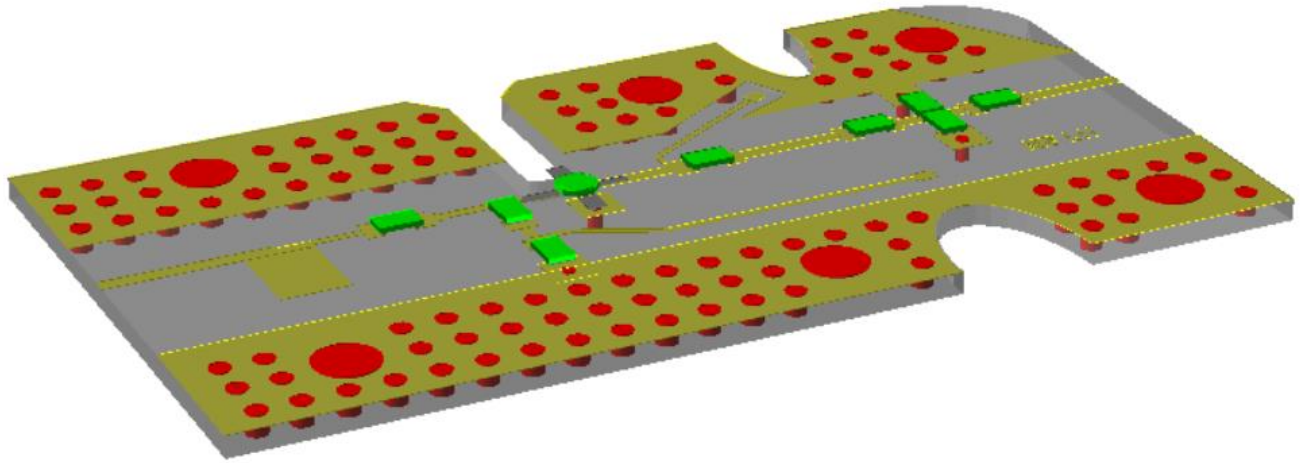


Complete LNA Design

Complete LNA Design Circuit Schematics and Layout







Summary

- Linear Simulation
  - S-parameters at Ports - and derived parameters ... Gain, NF
- Low Noise Amplifier as an Example to show:
  - Creating schematics
  - Data libraries
  - Editing schematic symbols (adding explicit ground nodes)
  - Creating graphs and adding measurements
  - Working with Circle Measurements
  - Measurements: S parameters, Noise, Gain
  - Tuning Parameters